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DEVELOPMENT AND DEMONSTRATION OF AN ENHANCED SPREADSHEET-BASED WELL LOG ANALYSIS SOFTWARE

Final Report
May 1998

By
W. Lynn Watney
John H. Doveton
W.J. Guy

October 1998

Performed Under Contract Subcontract G4S60821 and Contract No. DE-AC22-94PC91008

Kansas Geological Survey
Lawrence, Kansas

National Petroleum Technology Office
U. S. DEPARTMENT OF ENERGY
Tulsa, Oklahoma

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Prepared for
U.S. Department of Energy
Assistant Secretary for Fossil Energy

Rhonda Lindsey, Project Manager
National Petroleum Technology Office
P.O. Box 3628
Tulsa, OK 74101

Prepared by:
Kansas Geological Survey
1930 Constant Avenue, Campus West
Lawrence, KS 66047

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Program Objectives

The Advanced Class Work Program is a field-based research and demonstration program for demonstration of advanced or improved technologies identified in the Department of Energy's Class Field Demonstration Projects. The objective of the Advanced Class Work program is to conduct field demonstrations of technologies for which a small, incremental amount of work will produce or improve a transferable, useful technology for oil recovery. The goal of the program is to enhance the products of near-term Class projects and maximize the applicability and effectiveness of project results.

Background

PfEFFER (Petrofacies Evaluation of Formations For Engineering Reservoirs) is a well log analysis computer package that grew out of the "Super-Pickett" crossplot that was initially developed as part of the DOE funding (DOE/BC/1444313) "Depositional Sequence Analysis and Sedimentological Modeling for Improved Prediction of Pennsylvanian Reservoirs" conducted between 1990-1993 by the Kansas Geological Survey. The software was tested and successfully applied in Schaben Field, a DOE Class 2 Field Demonstration Project (DE-FE22-93BC14987) to assist in improving reservoir characterization and assessing reservoir performance. PfEFFER v. 1 was released in January, 1996 as a commercial spreadsheet-based well-log analysis program developed and distributed through the Kansas Geological Survey.

Solicitation Objectives

The objectives of this solicitation are to: 1. enhance the program and add major new modules to the software package; 2. conduct a field demonstration to demonstrate the program; and 3. transfer the technology to operators.

Scope of Work

Task 1: Enhance the PfEFFER software package by adding the following features:

1. Defining pay flag cutoffs and flow units;
2. Performing moveable oil plots and analysis;
3. Including shaly sand log analysis techniques for calculation of fluid saturations and display in modified Pickett plots;
4. Application of the Hough transform for simultaneous determination of Archie m and Rw;
5. Incorporation of log analysis techniques for secondary porosity analysis;
6. Developing forward modeling techniques to assist in integrating core and log data

Task 2: Develop major new modules to significantly augment PfEFFER capabilities including the following:

1. Link new software to reservoir fluid-flow simulators;
2. Link newly developed software to other mapping software and mapping refinements in PfEFFER.

Task 3: Conduct field demonstration of software application using the necessary reservoir data acquired from oil operators and construct a database.

Task 4. Perform technology transfer activities that include workshops, reports, presentations, or other methods to communicate results to interested parties.

PfEFFER Development Team

A geoscience team was assembled to conduct this contract work. Saibal Bhattacharya, a petroleum engineer, programmed cross section, coordinate conversion, and GridforSim modules, all components of PfEFFER Pro in Task 2. Paul Gerlach, a petroleum geologist, and Mr. Bhattacharya developed and tested procedures and software to link PfEFFER to DOE's reservoir simulator, BOAST 3. Simulation was applied to Schaben Field, a DOE Class 2 Field Demonstration Project. Geoff Bohling, geohydrologist/mathematical geologist, programmed new modules in PfEFFER 2.0 and developed the new format of the PfEFFER worksheet environment. John Doveton was responsible for the design of new modules in PfEFFER 2.0 and in conveying appropriate applications and theory behind the use of these modules. Bill Guy, petroleum geologist, applied PfEFFER to field studies and literature examples across the U.S. and internationally. He tested new modules and suggested refinements in the modules. Lynn Watney, petroleum geologist, provided project direction and reporting, design of modules included in PfEFFER Pro, and helped to implement applications of PfEFFER.

Greg Pouch, geohydrologist, developed a module in his GIS software program, WHEAT, to facilitate display of PfEFFER map data as a GIS benchmark map. Tim Carr, PI for Class 2 Field Demonstration Project in Schaben Field and PI for Digital Petroleum Atlas (DPA) assisted greatly in the technology transfer component of this contract by providing access to Schaben field data for developing and testing the use of PfEFFER and Excel to facilitate input file development for BOAST 3 and consenting to have Terry Field as part of the DPA. The Schaben Field study also provided financial support for Mr. Bhattacharya. Dana Adkins-Heljeson provided programming support for the transfer and organization of information included on the internet web sites. Office support for workshops and preparation of materials involved in technology transfer and sales related to this project were provided by Lea Ann Davidson and Melanie Cromwell (KU Energy Research Center). The Publication Sales Office of the KGS manages the sales and accounting of PfEFFER.

The Digital Petroleum Atlas is funded by the DOE, National Petroleum Technology Office under agreement DE-FG22-95BC14817. The Digital Petroleum Atlas (DPA) is located on the Internet at the URL: http://crude2.kgs.ukans.edu/DPA/dpaHome.html. Schaben Field is part of a DOE Class 2 Field Demonstration Project (DE-FE22-93BC14987). PfEFFER's web site is http://crude2.kgs.ukans.edu/PRS/software/pfeffer1.html.

Contacts for Project

Personnel contacts for this project include BDM, KGS, CRINC and company representatives, the later who are contributing funds and data to the project.

Dr. Mike Hefner — ph:918/337-4370
BDM Subcontract Administrator
BDM-Oklahoma
220 N. Virginia
Bartlesville, OK 74003

Dr. Susan Jackson — ph:918/699-2087 sjackson@npto.doe.gov
BDM Technical Representative
BDM-Oklahoma
P.O. Box 2565
Bartlesville, OK 74005

Ms. Barbara Armbrister ph:913/864-3344 fax:864-7789
Subcontractor's Contracting Representative
Assoc. Director
Center for Research, Inc. (CRINC)
341 Nichols Hall
The University of Kansas
Lawrence, Kansas 66045

Ms. Barb McClain ph:913/864-3965 fax:864-5317
Assist. Director
Kansas Geological Survey
1930 Constant Avenue, Campus West
Lawrence, KS 66047

Mr. Richard J. Gray , Resource Manager, Far West Mid-Continent Exploitation
Maria Henry ph:303/830-6044
Amoco Production Company
P. O. Box 800
Denver, CO 80201

Mr. Kevin S. McCoy ph:316/636-2741
President
McCoy Petroleum Corporation
3017 North Cypress
Wichita, KS 67226-4003

Dr. Wallie Souder ph:918/661-9726
Phillips Petroleum Company
274 Geoscience Building
Bartlesville, OK 74004

Mr. Phil Trumbly ph:281/584-3676
Senior Geologist
Vastar Resources, Inc.
15375 Memorial Drive
Houston, TX 77079

Synopsis of Project

PfEFFER 1.0 was available at the start of this contract. Features include the ability to read LAS digital files; construct a "Super Pickett" crossplot; map lines of water saturation, bulk volume water, and permeability on Pickett crossplots; generate depth plots of logs and calculated variables; calculate and present plots of lithology solutions; annotate capillary pressure data on the Pickett cross plot; and assemble wells and reservoir parameters to prepare plot files, grid and map the data. PfEFFER 1.0 can read data and perform analyses on individual wells and reservoirs, but also can manage multiple wells as separate workbooks and reservoirs as separate worksheets. Parameters from multiple wells are compiled into separate "project" workbooks for mapping. PfEFFER 1.0 is an add-in to Excel 5.0c.

PfEFFER Version 1.1 was released in June, 1997 at the end of the initial contract period. It represented a step toward the final product needed to fulfill the contract. Version 1.1 also ran as an add-in to Excel 5.0c. BDM granted a no cost extension through August, 1997 and again through November 28, 1997 in order to accommodate final development, provide documentation, test new modules and modify code to accommodate Excel 97, the newly released version of Excel.

PfEFFER now comes in two forms - PfEFFER 2.0 and PfEFFER Pro. PfEFFER 2.0 contains all of the basic modules. PfEFFER Pro contains additional modules, add-ins, that supplement the features of PfEFFER 2.0. Both versions are fully compatible with Excel 97. PfEFFER 2.0 includes an extensive suite of wireline log analysis tools providing the means to conduct standard and more advanced log analysis. PfEFFER 2.0 incorporates all of the new modules as specified in Task 1 —

> pay flag cutoffs, flow units, cluster analysis, moveable oil plots and calculations, shaly log analysis, Hough transform for simultaneous solution of Archie equation constants and formation water resistivity, secondary porosity, and petrophysical forward modeling.

PfEFFER Pro contains three additional modules addressing items in Task 2. New modules include GRIDforSIM, Cross Section, and map coordinate conversion. PfEFFER Pro facilitates derivation of key components used to construct input files for reservoir simulation. PfEFFER Pro is used to establish an integrated geological/engineering analysis of the reservoir. DOE's freeware reservoir simulation software, BOAST 3, is the simulation software of choice that was used to develop a tailored simulation input file and test reservoir characterizations. GRIDforSIM creates grids of data and provides means to visualize location of wells. The gridding procedure in GRIDforSIM calculates actual average values of grid cells utilized by a simulator, unlike standard mapping packages. GRIDforSIM also provides the means to view the grid, well locations, and land grid lines to facilitate evaluation of the gridding procedure, i.e., the advanced mapping features. In addition, PfEFFER Pro provides the ability to convert latitude-longitude coordinates to UTM. UTM (meters) coordinates are then converted to feet during the gridding operation to satisfy unit requirements used in BOAST 3. A cross section module is included to further define flow units and to visualize log and derived variables to help solve general stratigraphic problems.

Task 2 calls on PfEFFER to create a bridge to outside mapping programs. The PfEFFER map module builds plot files in project workbooks that can be easily placed on a Windows clipboard and copied to another Windows mapping application. An ASCII file can also be saved and imported into another mapping package. The GIS-based benchmark maps generated from PfEFFER plot files can be accomplished using a freeware program called WHEAT developed by Greg Pouch at the Kansas Geological Survey. A version of WHEAT was adapted to the Excel environment to facilitate its compatibility with PfEFFER. A GIS module was not established in PfEFFER for several reasons 1. size and complexity of GIS software and need to keep code centralized in the main software package; 2. development of well postings, land grid annotation, and coordinate conversion within PfEFFER Pro providing much of the functionality of GIS needed in mapping in PfEFFER; 3. ease in exporting plotfiles created in PfEFFER to other Windows mapping packages. Instructions for use of WHEAT including the import feature for PfEFFER plot files developed in this project are found on a WHEAT web page located at URL: http://crude2.kgs.ukans.edu/software/Wheat/whtmain.htm.

System requirements of PfEFFER 2.0 and PfEFFER Pro include use of an IBM-compatible personal computer with a 486 or higher processor and Microsoft Windows 95 operating system or Microsoft Windows NT Workstation 3.51 Service Pack or later. Windows 95 requires a minimum of 8 MB of memory. Windows NT Workstation requires a minimum of 16 MB of memory. A VGA or higher resolution video adapter is necessary. PfEFFER 2.0 add-ins and example files require 2 MB of hard disk space. PfEFFER 2.0 and PfEFFER Pro are designed to run as Add-ins to EXCEL 97. Manual and Pfeffhlp.hlp provide instructions on the installation of these add-ins.

PfEFFER 2.0 involves loading one add-in, pfeffer.xla, to Excel 97. This single add-in file combines several that were initially included in earlier versions of PfEFFER. PfEFFER Pro has three add-ins. PfEFFER 2.0 is distributed on three 3.5-inch diskettes including example files. All files are accessible in original uncompressed state for ease in getting started.

The PfEFFER manual is a ring-binder to permit ease in adding support information, documentation updates and examples. For those purchasing PfEFFER Pro, it facilitates addition of documentation as a supplement to PfEFFER 2.0.

New pricing for PfEFFER 2.0 is $345.00 plus shipping and handling. The price for PfEFFER Pro is set at $395.00 plus shipping and handling. Upgrades from earlier versions are $50 to go to PfEFFER 2.0 and $100 to go to PfEFFER Pro. PfEFFER 2.0 and PfEFFER Pro well logging software can be purchased from the Kansas Geological Survey, Attn: Publication/Sales, 1930 Constant Avenue - Campus West, Lawrence, Ks 66047; Phone: 913/864-3965; e-mail: pfeffer@kgs.ukans.edu; internet: http://www.kgs.ukans.edu

Goals of PfEFFER software

The goals in using PfEFFER remain the same as the original software including to resolve reservoir parameters that control performance; to characterize subtle reservoir properties important in understanding and modeling - hydrocarbon pore volume and fluid flow; to expedite recognition of bypassed, subtle, and complex oil and gas reservoirs; to systematically differentiate commingled reservoirs as an aid in defining reservoir management options to improve recovery; to assist in integrating large amounts of geological and engineering information to improve reservoir modeling; and to provide practical tools to assist the geoscientist, engineer, and petroleum operator in making their tasks more efficient and effective. PfEFFER can also be an important part in re-exploration in mature provinces where an objective is to refine log analyses of complex pore types residing in large untested stratigraphic intervals.

PfEFFER 2.0 focuses on basic and advanced petrophysics and PfEFFER Pro extends 2.0 to become an integrated reservoir characterization environment directed toward reservoir simulation.

A goal of PfEFFER Pro is to make simulation more commonplace and bring about more collaborative studies between engineers and geologists.

Implementing Work on Deliverables

Task 1. PROGRAM ENHANCEMENTS

Subtask 1.1. Definition of pay flag cutoffs, flow units, and layers suited for reservoir simulation and redesign of Home Area

a. Programmer is Geoff Bohling.
b. Home Area of the existing spreadsheet template redesigned to accommodate the new format.
c. Pay cutoffs added to the Parameter Field of the modified Home Area of the reservoir spreadsheet.
d. The redesigned Home Area also includes new columns for Vsh (estimated shale fraction), PAY (reservoir that meets cutoff criteria), and FLOW (flow unit designation).

Calculated value in each cell of the PAY column is oil fraction x incremental thickness. Cells in the PAY column that meet the cutoff criteria are colored to highlight the reservoir. Cutoffs are based on some or all of the following parameters: porosity, water saturation, Vsh, and/or bulk volume water. Cutoff values are also used to assign colors to cells in the porosity, water saturation, Vsh, and bulk volume water columns. The use of color highlights the heterogeneities in a reservoir and also provide a means to visually track changes within a reservoir, between commingled reservoirs, or among different well locations.
e. The FLOW column of the spreadsheet used to designate each cell to a flow unit or no flow barrier. Flow unit number is manually assigned by the user to each cell in the FLOW column.
f. Depth constrained cluster analysis (DCCA) is a "bonus" module that is used to assist with flow unit designation. DCCA classifies the analyzed interval according to variables selected by the user. DCCA uses standard Ward's cluster analysis with depth as a constraining variable.

Subtask 1.2. Movable oil plots and calculations

a. Programmer is Geoff Bohling.
b. New module and button called SXO.
c. Includes menu for selecting microresistivity log.
d. Additional parameters added to Parameter Area of PfEFFER spreadsheet to accommodate calculations including Rmf, Rmft, BHT, TD, and surface temperature.
e. Calculate and store information such as Sxo on another portion of reservoir worksheet.
f. Display log profile of Sw and Sxo.

Subtask 1.3. Shaly log analysis

a. Programmer is Geoff Bohling.
b. Goal is to transform Pickett crossplot using algorithms to "correct resistivity" using Aguilera methodology (see Aguilera, R., 1990, "Extensions of Pickett Plots for the Analysis of Shaly Formations by Well Logs, The Log Analyst, p. 304-313).
c. Menu designed to select shaly sand option.
d. Shows transformation with option to switch back to original Pickett crossplot (changes are simultaneous and automatically updated).
e. Labels added on Pickett crossplot.
f. Includes lithology plot incorporating results from the analysis.

Subtask 1.4. Application of the Hough transform for simultaneous solution of Archie equation constants and formation water resistivity

a. Programmer is Geoff Bohling.
b. Goal is to solve simultaneously for water resistivity and Archie equation constants by using a Hough transform to map data into "parameter space." The technique is explained by Doveton in Chapter 2 of "Geologic Log Analysis Using Computer Methods" (AAPG, 1994).
d. Shows Hough transform as mapped crossplot in water resistivity - Archie "m" space.

Subtask 1.5. Incorporation of log analysis techniques to analyze and display "secondary porosity"

a. Programmer is Geoff Bohling.
b. Additional program added to contrast "primary" porosity as measured by the sonic tool with "secondary" porosity signified by differences with the total porosity measured by density and neutron devices.

Subtask 1.6. Petrophysical forward modelling, generating synthetic petrophysical logs, and alternative model scenarios

a. Programmer is Geoff Bohling.
b. Simulate resistivity curve based on empirical relationships with rock texture/facies/beds obtained via cores and core analyses. Utilize capillary pressure information to estimate resistivity response, modeled after work of Pittman, E.D., 1992, AAPG Bulletin, v.76, no. 2, p.191-198.
c. Facilitate reconciliation of core and logs to test and experiment via multiple scenarios to help verify petrophysical models, e.g., response of thin beds, changing water saturation and shale content. Develop user-friendly interface to permit recognition of nonintuitive and subtle results.
d. Module can be used to help develop and calibrate permeability profiles using cores and extend permeability predictions.

Task 2. New Major Program Modules

Subtask 2.1. Programmed linkage of well log analysis and BOAST III reservoir simulator. Output of rock and fluid properties data from new software directly into BOAST III. Retrieval and display of output from BOAST.

a. Programmer is Saibal Bhattacharya.
b. Visual Basic code written to acquire, calculate and manage input data for use in DOE's reservoir simulator, BOAST 3.
c. A user-friendly interface developed to compute grids of zone/layers for use in the reservoir simulator. Grid cell values are averaged.
d. Additional components originally covered in Subtask 2.2 including land-grid overlay, coordinate conversion, and display of grids and wells together.
d. Module tested in Schaben Field. Also being applied to Terry Field. Results are available through the Digital Petroleum Atlas located at URL: http://crude2.kgs.ukans.edu/DPA/Schaben/schabenMain.html and http://crude2.kgs.ukans.edu/DPA/Terry/terryMain.html

Subtask 2.2. Link new software to other Mapping Software and Mapping Refinements in PfEFFER

a. Programmer is Greg Pouch.
b. GIS software, "WHEAT Version 3," developed by Greg Pouch runs under Excel. Decided to keep GIS components in WHEAT and write module in WHEAT to facilitate links to PfEFFER. Keeping GIS system together would facilitate future modifications and updates. WHEAT is available as freeware on Kansas Geological Survey's home page (http://crude2.kgs.ukans.edu/software/Wheat/whtmain.htm).
(1) GIS mapping package of WHEAT allows the user to produces "GIS format" "benchmark" maps which include
(a) symbols (such as for producing and dry wells)
(b) text (such as well names and lease names)
(c) lines (such as pipelines and transects)
(d) polygons (such as lease areas and outcrop/subcrop areas)
(e) marginal information such as title, author, and date
(2) Wheat includes utilities to aid in mapping
(a) import/export of line/polygon data from/to three simple formats for compatibility with other mapping packages
(b) projection from one coordinate system to another
(c) conversion of point locations from Public Land Survey coordinates to UTM coordinates, for Kansas only.
(3) GIS "Benchmark" map can be placed in PfEFFER spreadsheet as image.

Task 3. Field Demonstration of Software Applications

Subtask 3.1. Formation of industrial board of participating companies.

Representatives designated for the participating companies: Amoco, McCoy, Phillips, and Vastar (see Contacts for Project).

Subtask 3.2. Data acquisition and analysis.

a. The databases were acquired from four participating companies and analyzed using PfEFFER. Data and results remain confidential for three of the projects except data contributed by McCoy Petroleum Company from Terry Field located in Finney County, Kansas (Figure 1). PfEFFER analyses was conducted on the primary zones of interest as agreed to with the operator. These zones included the Farley and Dewey Limestones from the Lansing-Kansas City Groups, Altamont and Pawnee from the Marmaton Group and the St. Louis Limestone. (Figure 2).

Introduction to Terry Field

Terry Field is prolific oil field, containing twelve pay zones that range from a series of thin, cyclic carbonate reservoirs in the Upper Pennsylvanian Lansing-Kansas City and Middle Pennsylvanian Marmaton Group, sandstone reservoirs in the Lower Pennsylvanian Morrowan Kearney Formation, and a carbonate (oolite) reservoir in the Upper Mississippian St. Louis Formation.

Terry Field is currently under primary recovery and production is commingled. As shown in Table 1 below, the field has been prolific, producing nearly 3 million barrels from 25 wells through late 1996.

Table 1. Vital statistics of Terry Field

Discovery Well: Berexco, #1-34 Mike Rome
Location: Nw Se Se, 34-T22S-R34W
Discovery Date: 11/20/91
Depth: 4900' RTD
Trap Type: Structural
Field Size: 1,600 acres
Productive Wells: 25
Abandoned Wells: 0
Cumulative Oil: 2,862,530 bbls as of 12/1/96
Cumulative Gas: 0 mcf as of 12/1/96

Objectives in PfEFFER Analysis of Terry Field

The operator of Terry Field, McCoy Petroleum, desires to improve their understanding of the reservoir heterogeneity to help explain current production trends and to define optimum strategies for waterflooding and well re-completion.

Methodology in PfEFFER Analysis of Terry Field

Data were obtained on Terry Field that included well log, sample descriptions, core analyses, well test and completion data, and production information. Many of the well logs were available in digital form. Several logs were sent out commercially for digitizing. Once all the log data was in digital form, this information was read into PfEFFER for analysis. Several types of PfEFFER worksheets were prepared including separate ones for each reservoir as well as the gross interval. The individual reservoir worksheets focused on individual reservoir characterization while the gross interval worksheets were developed to investigate variations among the reservoirs.

Pickett cross plots were constructed with annotations of perforations and production. These plots were used to determine cutoffs of porosity and water saturation for pay, net pay thickness, and to define minimum bulk volume water (BVW) and possibly irreducible values of BVW. Inference were made about pore types and presence of transition zones and oil:water contacts based on patterns and trends expressed when successive points on the Pickett cross plot are connected by depth (as done automatically by PfEFFER).

Pickett cross plot results were tested and validated using available DST, production, and core analyses. Cutoffs for pay were defined for each reservoir. Values of porosity and water saturation associated for a minimum BVW were defined as variables for mapping. Various depth-related information including log response and derived information such as BVW, computed porosity, and pay were selected to display in color image cross sections.

Reservoir characterization in Terry Field is a prerequisite for two future reservoir simulations, one in the Altamont Limestone and the other in the St. Louis Limestone, both distinct candidates for waterflooding. PfEFFER analysis has been particularly helpful in assessing variation in pore type and other heterogeneities involving reservoir continuity and conformance. These will be very important to future reservoir simulation.

The operator consented to make analysis of Terry Field available to the public on the Digital Petroleum Atlas home page (http://crude2.kgs.ukans.edu/DPA/Terry/terryMain.html). Paul Gerlach and Dana Adkins-Heljeson, members of the Digital Petroleum Atlas team, worked with Bill Guy, preparing Pickett crossplots, defining pay and water saturations, constructing individual pay map (porosity-feet and structure, see Figure 3), making cross sections, and developing means for users to download digital log, well completion, and production history from the web site (Figure 1).

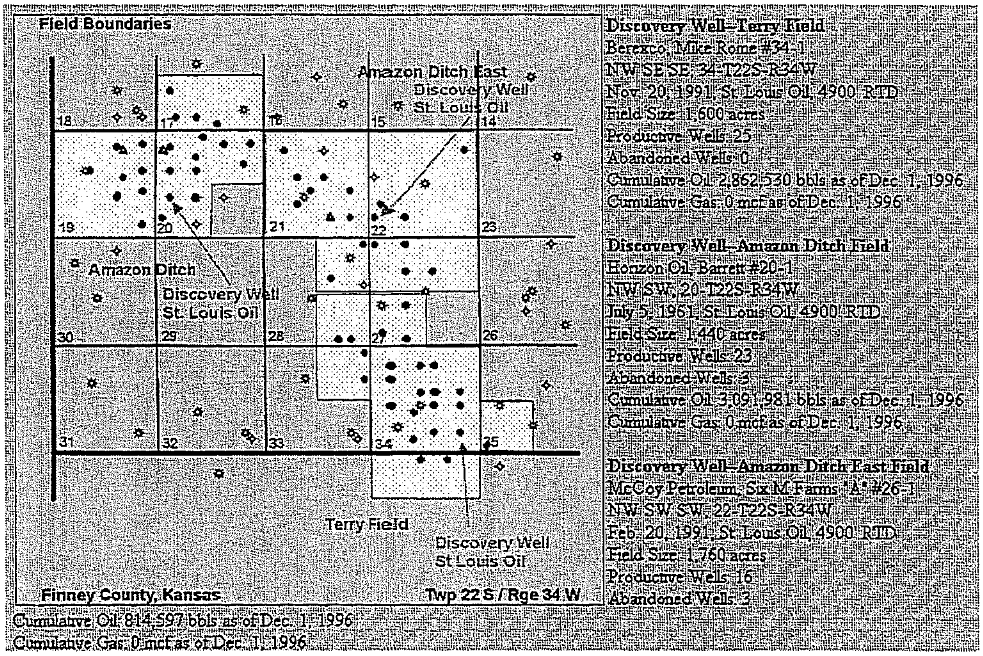
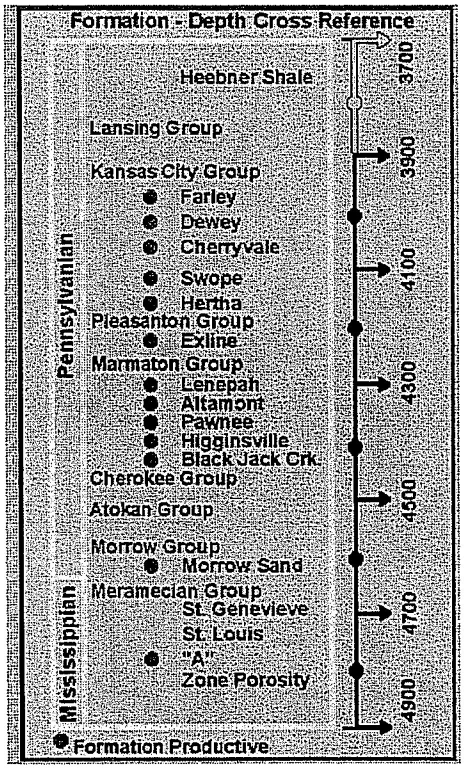


Figure 1. Terry Field location map from Terry Field site on Digital Petroleum Atlas.



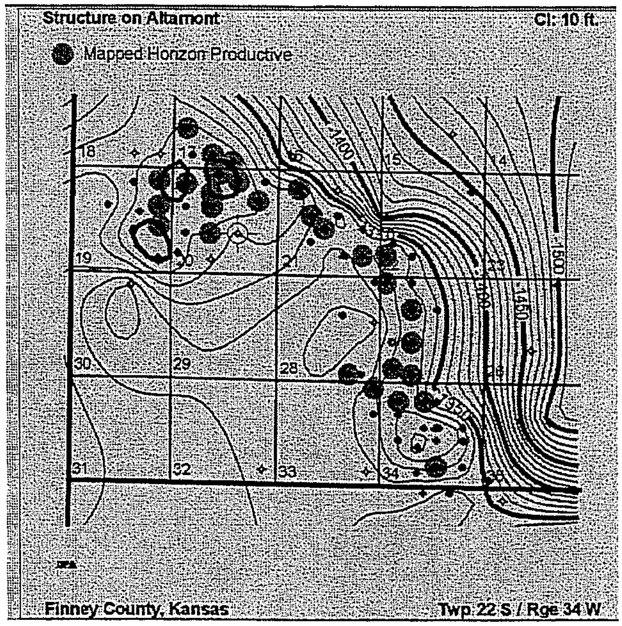


Figure 2. Stratigraphic chart and producing horizons in Terry Field (from Digital Petroleum Atlas).
Figure 3. Structure map on top of Altamont Limestone in Terry Field (from Digital Petroleum Atlas).

Results of PfEFFER Analysis in Terry Field

PfEFFER has enabled an efficient, consistent characterization of the reservoirs that are tailored to specific pore types and heterogeneities. The PfEFFER program worked very well in all of the reservoirs examined in Terry Field. Knowledge of the type of porosity is will be critical to the success of future improved recovery options employed in the field. Pore types encountered include interparticle, vug, microcrystalline, and fossil moldic. Cutoffs of BVW and water saturation have been used to isolate and characterize pay. These results provide constraint in evaluating relative contributions of production from commingled pays that typify this field. Well testing and tracers are recommended to confirm these results.

Testing and applying PfEFFER's GRIDforSIM module was conducted on several reservoirs in Terry Field. Results will be useful to eventually establish input files for reservoir simulation.

A potentially underproduced carbonate reservoir called the Cherryvale Formation in the Kansas City Group has not been widely tested and or perforated in Terry Field. Pickett cross plots have indicate multiple discontinuous pay zones in the mid and lower portions of this carbonate cycle. While this carbonate unit is an overall shallowing upward (regressive) cycle (4^{th}-order, 100 ky-500 ky), minor cyclicity (5^{th}-order) within this succession apparently results in recurring shallowing and multiple intervals of grainstone (see Cherryvale core description from Victory field in Figure 3). These grainstones are preferred sites of reservoir development although primary porosity is usually greatly modified by diagenesis.

In lower shelf settings (southern Kansas bordering the Anadarko and Arkoma Basins), carbonate units are thicker and the internal stratification is more complex, i.e., preservation of multiple minor cycles. Such is the case at Terry Field. Significant minor cyclicity has been observed in core from the Cherryvale Formation in Victory Field in Haskell County, located south of Terry Field.

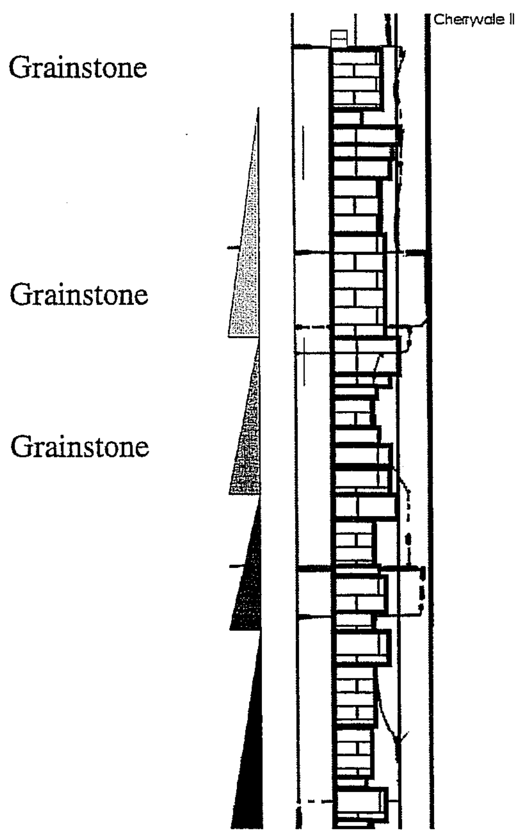
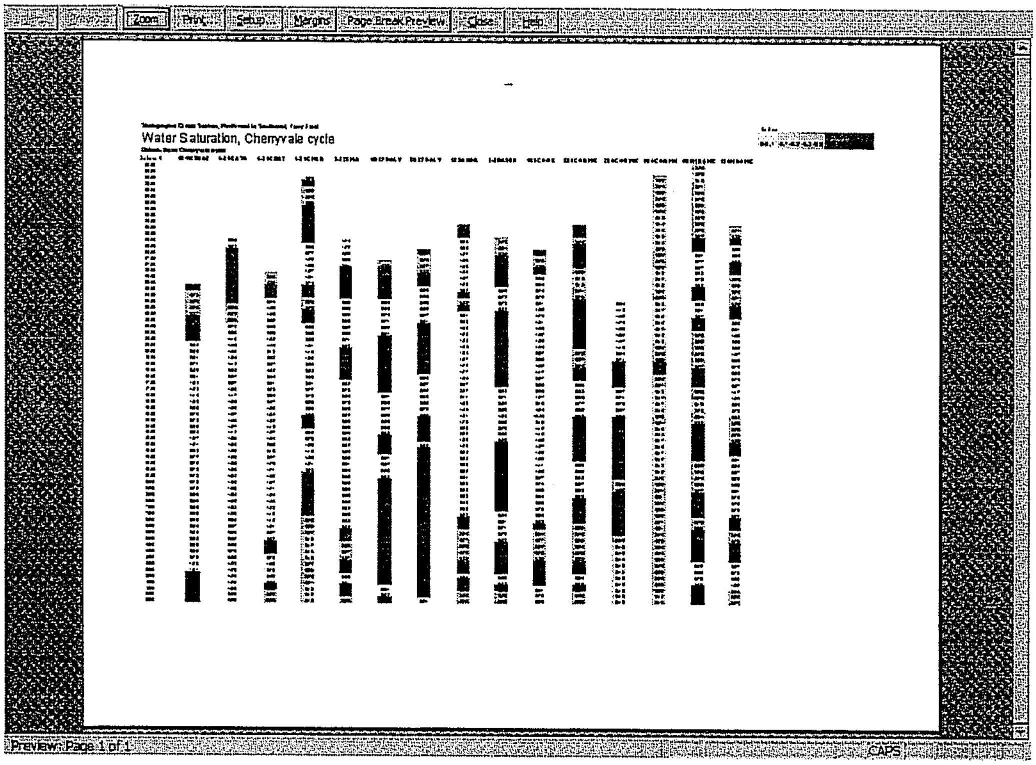


Figure 3. Graphic core profile of Cherryvale Formation in Amoco Cox #2-A in Victory Field, Haskell County, Kansas. Section is 40 feet thick. Wedges along left margin indicate intervals of minor shallowing-upward cycles.

A color image cross section of porosity in the Cherryvale Formation running through the axis of the Terry Field illustrates multiple intervals of porosity development (Figure 4, upper). PfEFFER assisted in rapidly analyzing this zone and to lead to recognition of the potential for additional pay in this interval. Possible recompletions are indicated. Pickett crossplots further describe and isolate the locations of these stacked pays. The information helps evaluate the spatial variability and relative quality (continuity and conformance) of the reservoir.

Figure 4 (lower) illustrates further application of the color image cross section module to the Middle Pennsylvanian Altamont Limestone of the Marmaton Group in Terry Field. In this example, water saturation is depicted in color with low Sw shown indicating "sweet spots" in this significant producing interval in the field



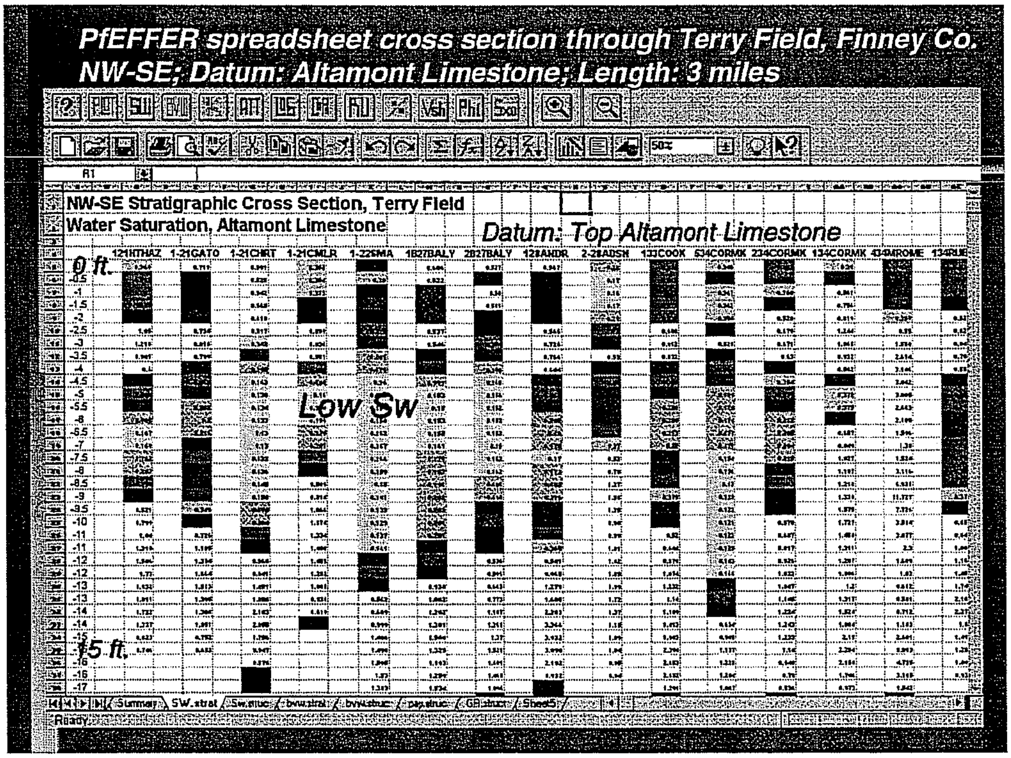


Figure 4. Upper diagram (previous page) is a screen capture of an Excel print preview of a NW to SE stratigraphic cross section depicting water saturation in the Cherryvale Formation in Terry Field. Datum is base of Cherryvale. Labeling in feet above lower datum shown along left margin. Three-mile long cross section reveals several potential pays in the mid and lower portions of the unit. Production is currently limited to the southern end of the section. Lower diagram is a Powerpoint version of a cross section through the Altamont Limestone, a prime candidate for waterflooding and reservoir simulation. Uncolored areas exceed 50% water saturation. Lighter grays are low water saturation. Originals are in color.

b. PfEFFER was utilized in characterizing the Mississippian carbonate reservoir in Schaben Field, a DOE Class 2 Field Demonstration Project located in Ness County, Kansas. The new PfEFFER Pro module GRIDforSIM was developed in the context of defining an optimum means to prepare an input file for a reservoir simulation. DOE's BOAST 3 reservoir simulator was used to build a simulation of 35 wells. This was done successfully and is being used to drive activities in Phase 2 of this Class 2 field demonstration project (Simulation output, Figure 5). Simulation results were presented and published in Proceedings of the Twelfth Oil Recovery Conference, Bhattacharya et al., 1997 (see publications list below). Paper is also included in the Appendix. Results of the Schaben study can be accessed at its web site on the Digital Petroleum Atlas.

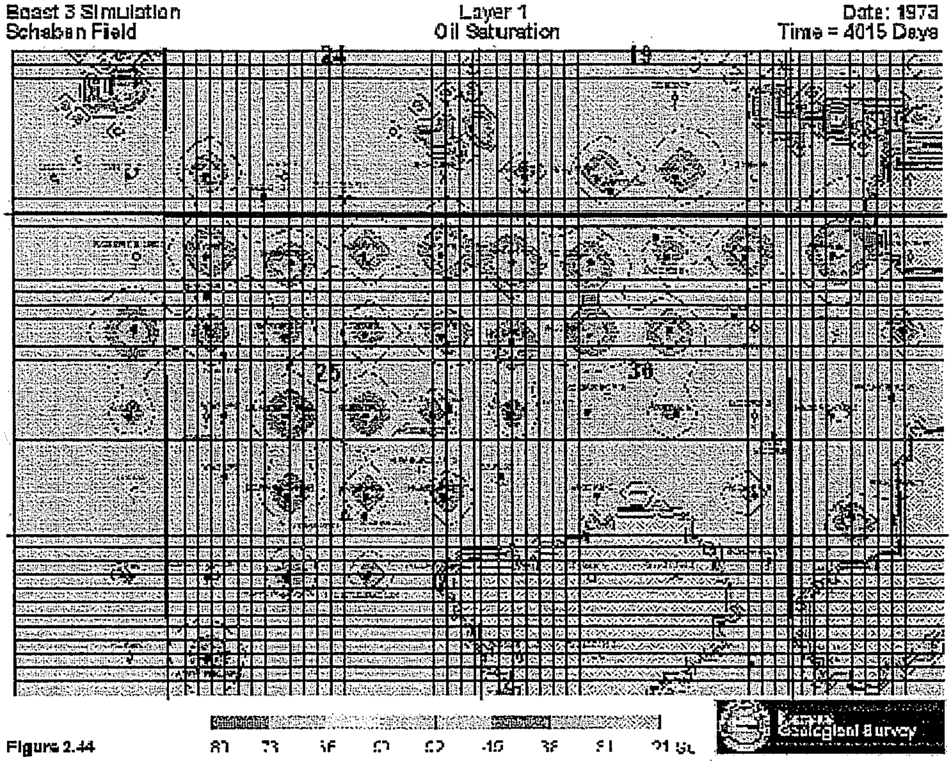


Figure 5. Remaining oil saturation in Schaben Field. Results from BOAST 3 reservoir simulation as published in the Digital Petroleum Atlas.

c. PfEFFER analysis was also applied to characterization of the lower Morrow Sandstone in <u>Arroyo field</u> in Stanton County, Kansas (Figure 6). In particular, the design and testing of the cross section module was developed using wells from Arroyo Field. Results were presented in a paper at the Fourth International Technical Reservoir Characterization Conference (Watney et al., in review; see publications list below). The application is summarized below and in the paper included in the Appendix.

<u>Summary of Arroyo Field Setting</u>: Arroyo Field, operated by J.M. Huber Corporation, is a prolific field, discovered in 1992 through application of subsurface methods. Cumulative production exceeds 651,000 barrels of oil and 21 billion cubic feet of natural gas. Arroyo Field is a combination structural stratigraphic trap, currently containing 6,240 proven productive acres with 24 oil and gas wells and 3 dry holes. The field contains two reservoirs, the Lower Morrow sandstone and the St. Louis Limestone (oolite). The Lower Morrow sandstone is located at approximately 1715 m (5,400 ft) below the surface. The sandstone ranges from 0 to 19 m (0 to 60 ft) thick and is lenticular throughout the field. The porosity of the sandstone ranges up to 20% and averages 14%. All positions of the sandstone have been perforated in the field, some wells reported as only gross intervals. Initial reservoir pressure was 1,434 psi.

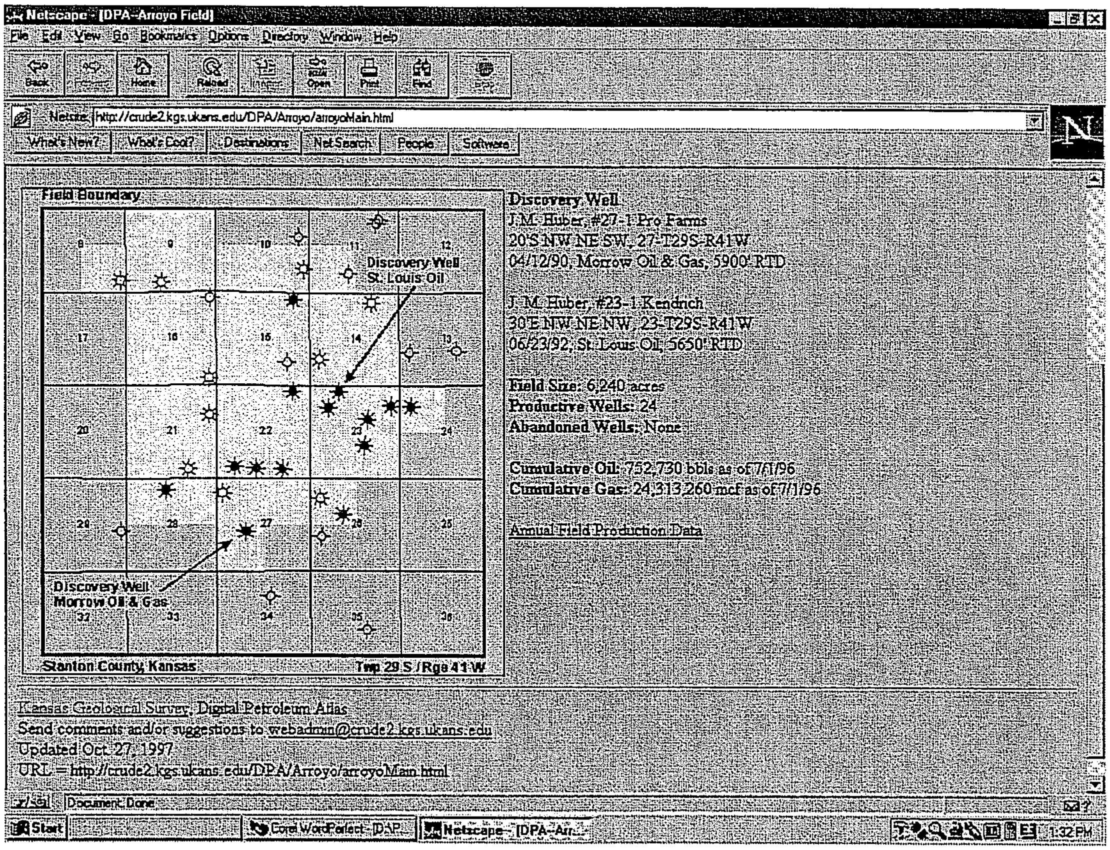


Figure 6. Base map for Arroyo Field taken from Digital Petroleum Atlas web site.

The upper portion of the lower Morrow sandstone has produced only natural gas and the lowest portion has produced significant amounts of both oil and gas. No water has been produced in any of the wells. Also, no oil:water contact has been recognized. The reservoir drive appears to be gas expansion. This provided an opportunity to examine BVW and apparent changes in pore type since the reservoir was near or at irreducible water saturation.

A considerable amount of supporting data on Arroyo Field including digital well logs, completion reports, and interpretive maps, cross sections, and synthetic seismograms are included in a digital publication of this field on the Kansas Geological Survey's Digital Petroleum Atlas located on the Survey's Internet Home Page (URL=http://crude2.kgs.ukans.edu/DPA/Arroyo/arroyoMain.html).

The lenticular Lower Morrow sandstone is comprised of a series of upward-coarsening, marginal marine shoreface deposits that are mostly confined to within one-half mile wide meandering valley, up to 48 m (150 ft) deep. The sandstone was previously correlated and subdivided into five separate sandstone-dominated genetic units (1, 3, 5, 9, 11) using gamma ray, porosity, and resistivity logs and one spectral gamma ray log. Each genetic unit is delineated by bounding surfaces usually characterized by abrupt changes in lithofacies. The surfaces either represent subaerial exposure or flooding surfaces or both. Each genetic unit is believed to represent temporally distinct episodes deposition, i.e., a genetic unit. Only several of the genetic units are developed at any particular location in the field.

The sandstones were deposited in a meandering valley system during overall rise in sea level. Maps of each genetic unit record episodes of infilling of this valley, each unit with varying geometries and sand abundance and quality. The lowest sandstones are more limited in distribution, filling only the lowest (deepest) portions of the valley, while the higher sandstones locally extend beyond the confines of the valley. For these reasons, the stratigraphic distribution was believed to be a controlling factor on flow unit definition.

Petrofacies Analysis in the Arroyo Field: Reservoir characterization and modeling are ongoing procedures utilized as the reservoir is developed. Well log data and occasional cores provide the fundamental stratigraphic information critical to delineating flow units, a primary objective of reservoir characterization. Flow units are correlatable and mapable regions in the reservoir that control fluid flow. Their distinction is usually centered on comparing permeability and porosity information. This classification is refined as fluid recovery, pressure data or chemical fingerprinting become available. Often times, particularly in older fields, production is commingled and cannot be used to substantiate flow units. Moreover, the costs of extensive fluid and pressure testing are not economic. The question examined in the study is whether the traditional definition of flow units can be modified to include additional information obtained from basic suites of well logs. An approach referred to as petrofacies analysis utilizing PfEFFER was used to extend the use of well logs to maximize information that relates to pore type and fluid flow. In particular, the utility of distinguishing vertical and lateral trends and patterns of irreducible bulk volume water, water saturation, and porosity was evaluated as tools to improve definition of flow units using well logs. Petrofacies are defined as portions of the reservoir that exhibit distinctive geological facies and petrophysical attributes.

The steps taken in this analysis were to correlate the reservoir interval, Lower Morrow Sandstone, establish stratigraphic subdivisions and lithofacies, prepare maps and standard well log cross sections using available subsurface control, and initially define flow units. This information is then compared with the production and test data to check for consistency and correlations.

Another step examined in this study was to extract additional information about pore types and fluid saturations utilizing PfEFFER. The Pickett plot indicated changes in pore types while porosity varied little resulting in changes in bulk volume water, water saturation and productivity. Continuity of possible flow units was evaluated through examination of changes in water saturation and BVW with elevation of the reservoir. Co-variation suggests possible fluid continuity and reservoir conformance. Points on the Pickett crossplots were annotated with color according to stratigraphic zonation and possible flow units (Figure 7). Clusters, "elbows" patterns, and bands of points indicated greater similarity in "petrofacies" within these zones. An additional tool using depth constrained cluster analysis (DCCA) was used to substantiate the grouping of these stratigraphic units and prospective flow units as observed on the Pickett cross plots. This led to the development of the Cluster module. This study suggested that the added information on pore types, vertical reservoir conformance, and fluid/reservoir continuity provided by petrofacies analysis is important in assessing flow units.

Petrofacies analysis is used in this example to extend an initial stratigraphic analysis of a sandstone reservoir in an attempt to define flow units. The ultimate objective of this reservoir characterization will be to conduct a reservoir simulation of the field to help evaluate future production options.

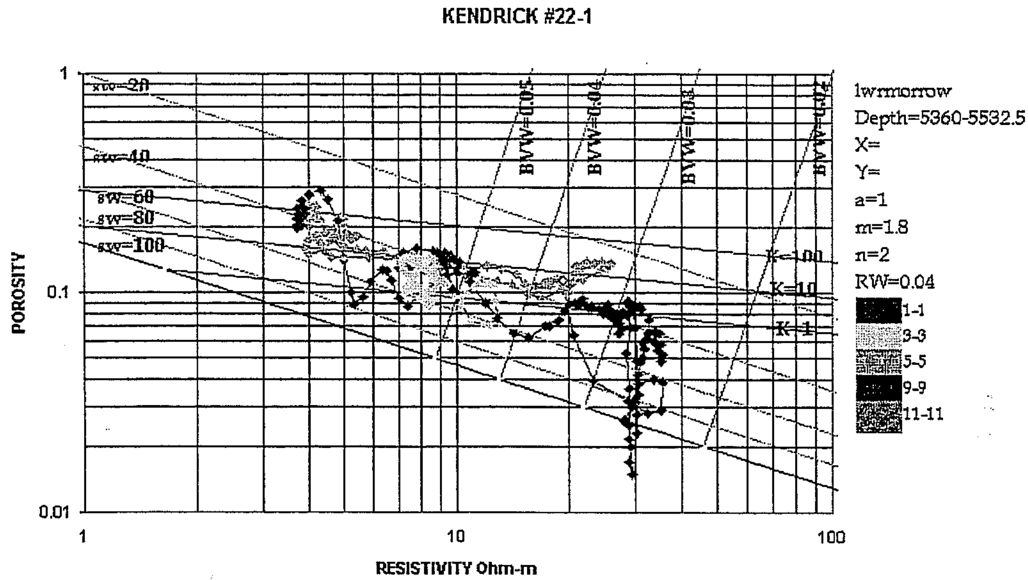


Figure 7. Pickett crossplot from Kendrick 22-1 in Arroyo Field. Points are annotated with color (original in color) corresponding to stratigraphic zone number. Question is whether a stratigraphic zone can serve as a flow unit. Clustering of points corresponding to stratigraphic unit at least suggest that these zones have similar properties. Adjacent wells reveal shifts in these patterns as properties of these stratigraphic zones change laterally.

c. Extended Application of PfEFFER to Examples Outside of Kansas. Hundreds of individual wells and reservoirs from throughout the U.S. (outside of Kansas) were analyzed through the contract period by Bill Guy. Objective was to build a data base of examples showing variability of reservoir types at sites where complementing information is available to substantiate the PfEFFER analysis. An objective was to examine situations where problems in well log analysis exist. The major issues identified are characterization of microporosity in sandstones and carbonates and shaly, low resistivity sandstones. Significant results are summarized here and nine examples follow.

PfEFFER was used to analyze 22 examples from the volume titled, "Productive Low Resistivity Wells of the Offshore Gulf of Mexico" published in 1993 by the New Orleans Geological Society and Houston Geological Society and "Low-Resistivity, Low-Contrast Productive Sands" short course by Sneider and Kalha published by AAPG in 1995. Pickett cross plot annotated with gamma ray or photoelectric effect (Pe) consistently distinguished productive, low resistivity sands in these examples. Productive intervals typically form distinctive patterns and trends on the Pickett cross plot regardless of whether they are low resistivity pays or not. The low resistivity is related to the contributions of relatively high shale or clay content resulting in a relatively high bound water content and high BVW. Yet, the hydrocarbon effect, albeit masked, is still present. The clustering of points on the Pickett crossplot of the low resistivity pay intervals is typical of what has been observed in "normal" pay zones except for their overall displacement on the crossplot. The presence of clay or shale which is often verified by the gamma ray curve can occur in the reservoir as thin laminations, clasts, burrow-fillings, pore fillings, pore linings, or clay grains (Sneider, 1982). Knowledge of the type of clay and shale distribution in the reservoir helps to substantiate the log analysis results. The shaly sand module in PfEFFER provides several models from which to correct the resistivity for the effects of shale and to accomplish the designation of pay.

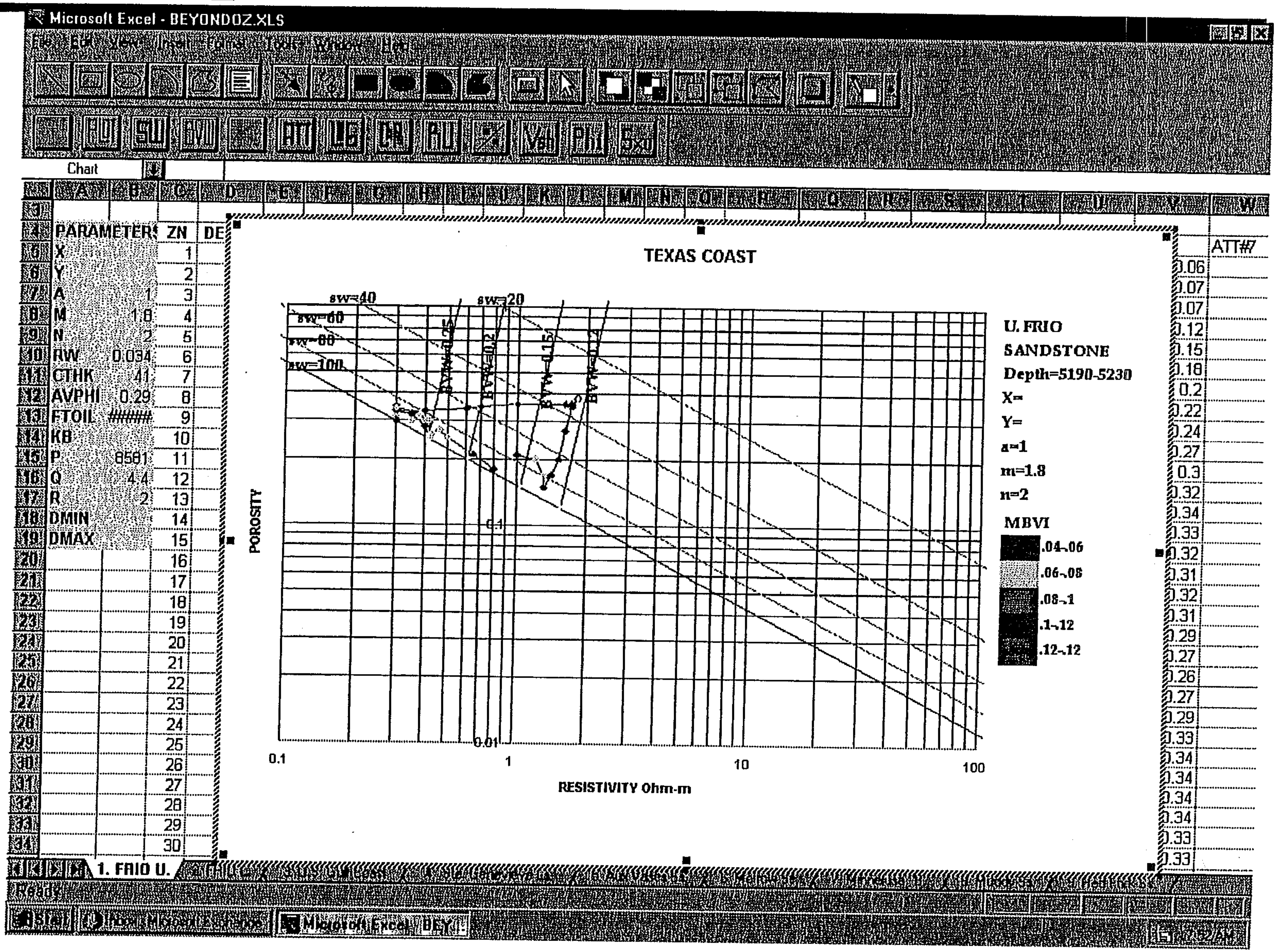
PfEFFER was also used to analyze many examples from the volume "Hydrocarbon Production from Low Contrast, Low Resistivity Reservoirs, Rocky Mountain and Mid-Continent Regions - Log Examples of Subtle Pays," published by the Rocky Mountain Association of Geologists in 1996. These examples not only include shale or clay filled sandstones, but carbonate reservoirs containing microporosity and the very fine grained sandstones. As in the Gulf Coast examples, the producing reservoirs have low resistivity because of the bound water in microporosity. In these examples, microporosity was contributed by clays, shales, or carbonates.

Evaluation was also performed on examples from a report, "Tight Gas Sands Log Interpretation - Problem Study," prepared by the CER Corporation (Las Vegas, Nevada) and published by the Gas Research Institute in 1983. The reservoirs include the Pictured Cliffs and Dakota Sandstones (San Juan Basin), the "Clinton" (Medina) sandstones (Appalachian Basin), and the Cotton Valley sandstones (Louisiana-Texas Area). PfEFFER provided recognition of pay intervals in these examples even though they have high BVW and water saturation. Examples in the Cotton Valley Trend of Texas-Louisiana in the CER study resemble well data submitted by Vastar in support of the PfEFFER project. CER Corporation recommended more extensive log-core studies to better determine the lithology and more studies in order to correct low resistivity readings and decrease values of calculated water saturation.

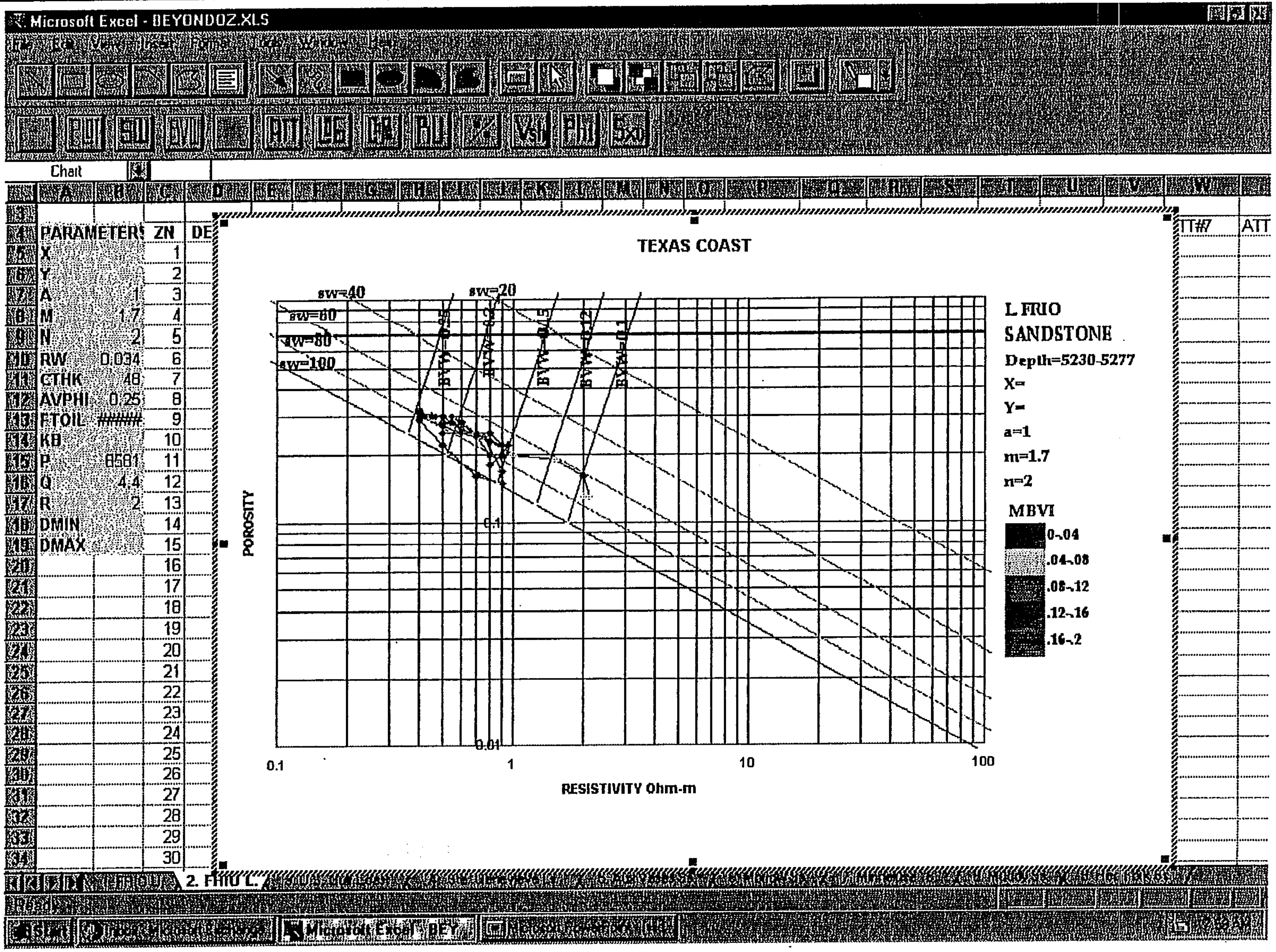
Nine examples were chosen from these and other published reports and are summarized below. These examples were also shared during several workshops and were sent to PTTC Regional Resource Centers accompanying the demonstration copy of PfEFFER.

(Nine pages follow each consisting of a combination Powerpoint slide and outline. Each contains a Pickett crossplot and summary of interpretation to illustrate applications of PfEFFER to examples beyond Kansas.)

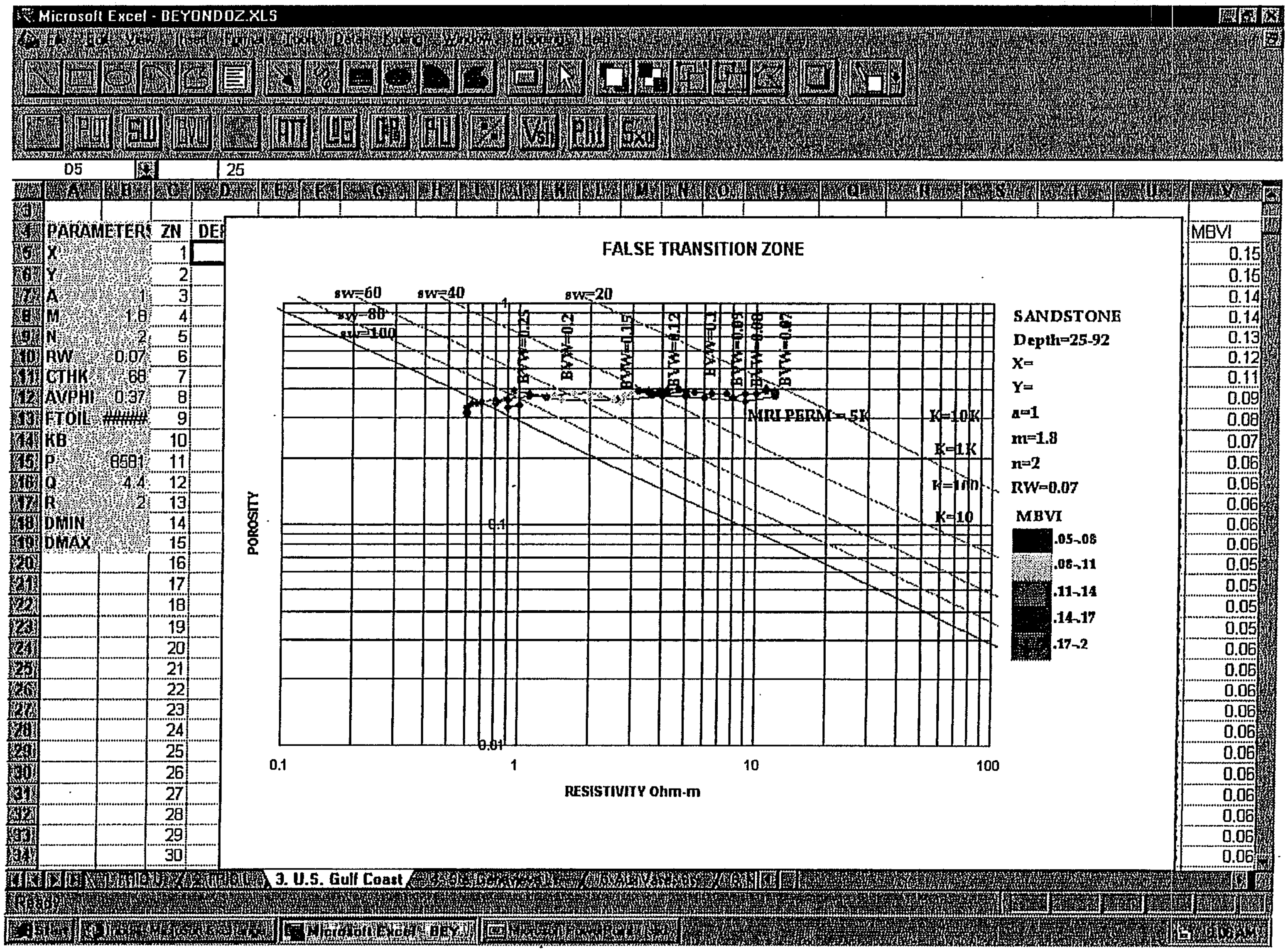
1. Upper Frio Sandstone



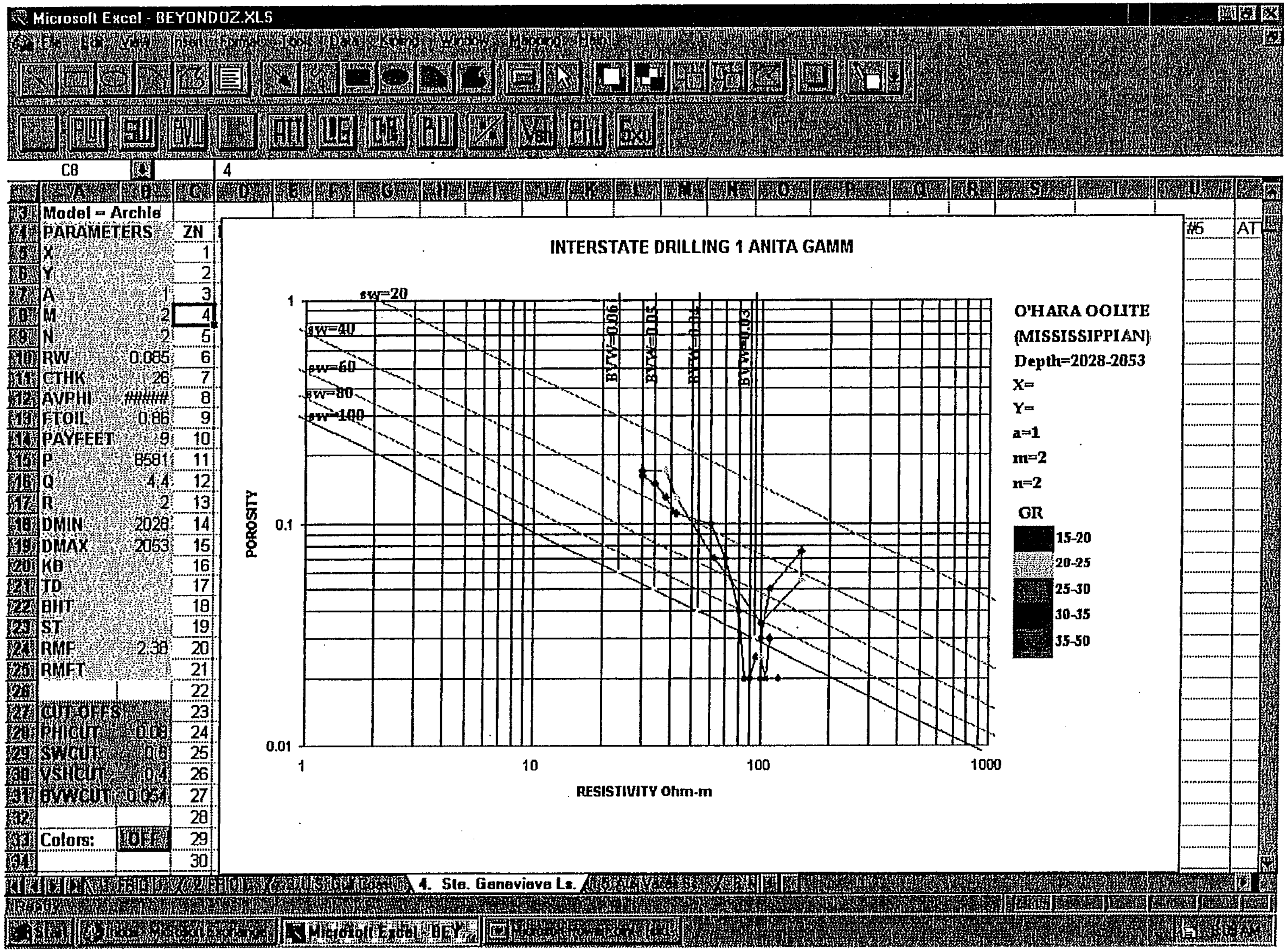
2. Lower Frio Sandstone



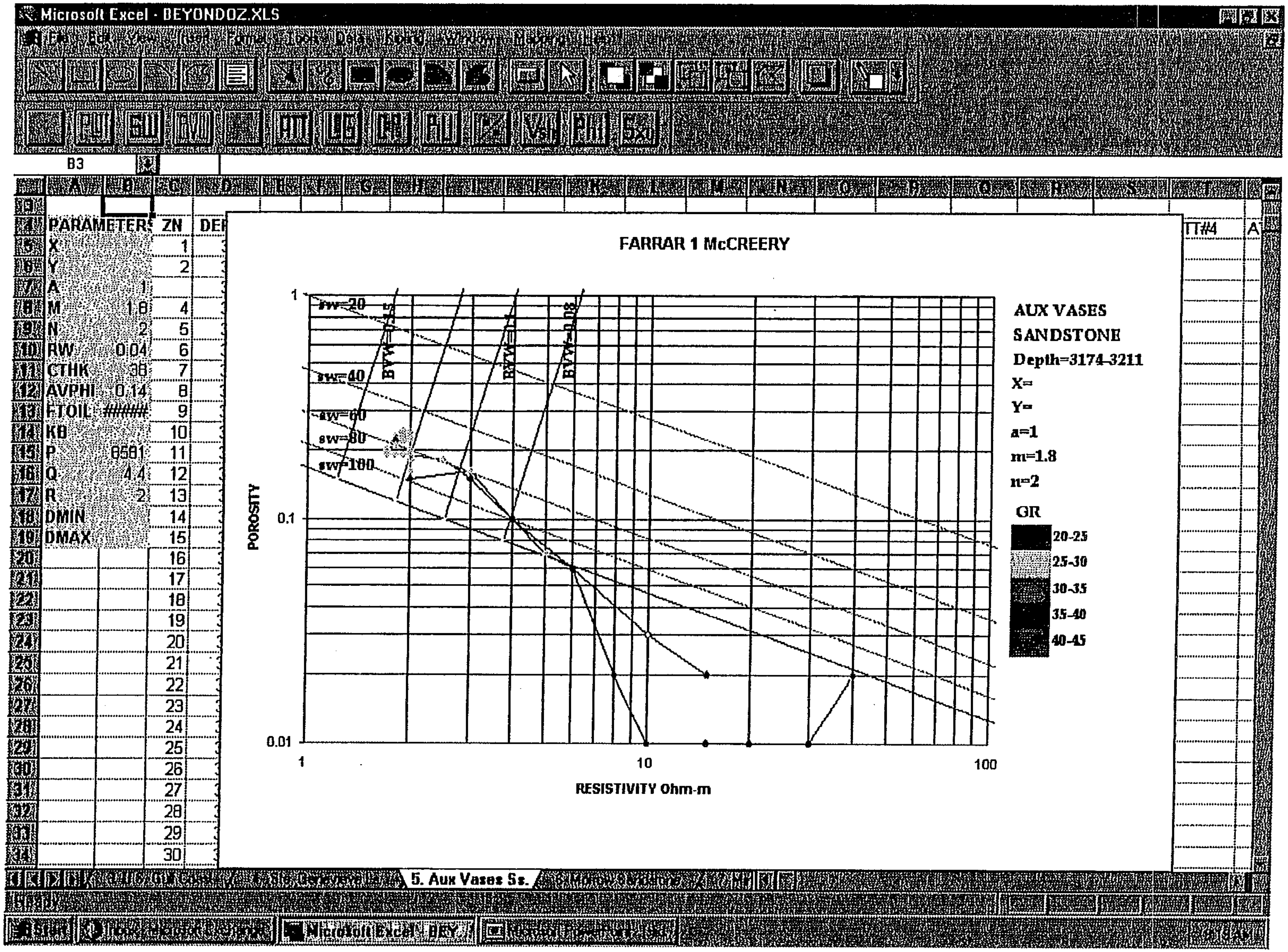
3. Gulf Coast Sandstone



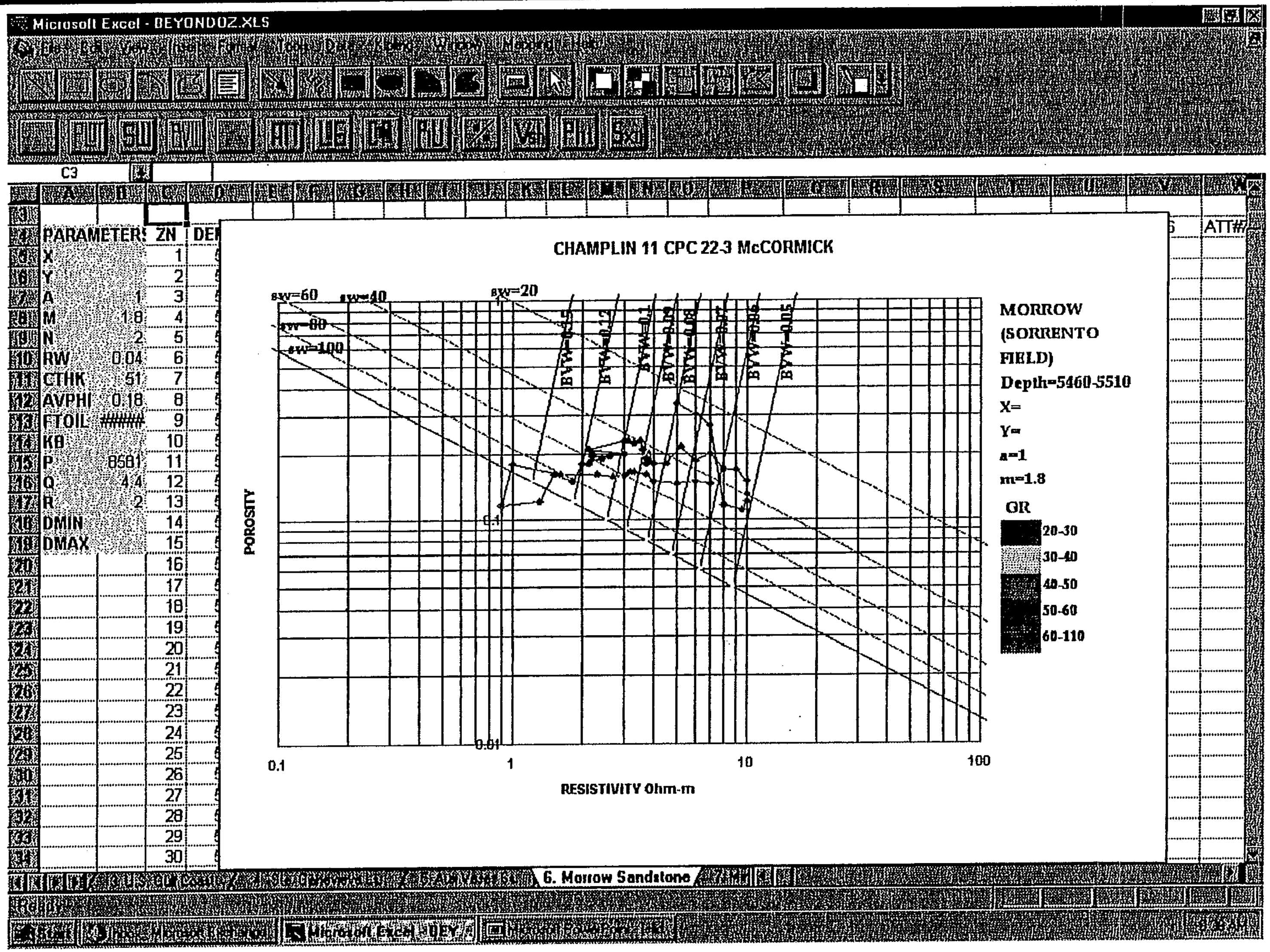
4. Ste. Genevieve Limestone



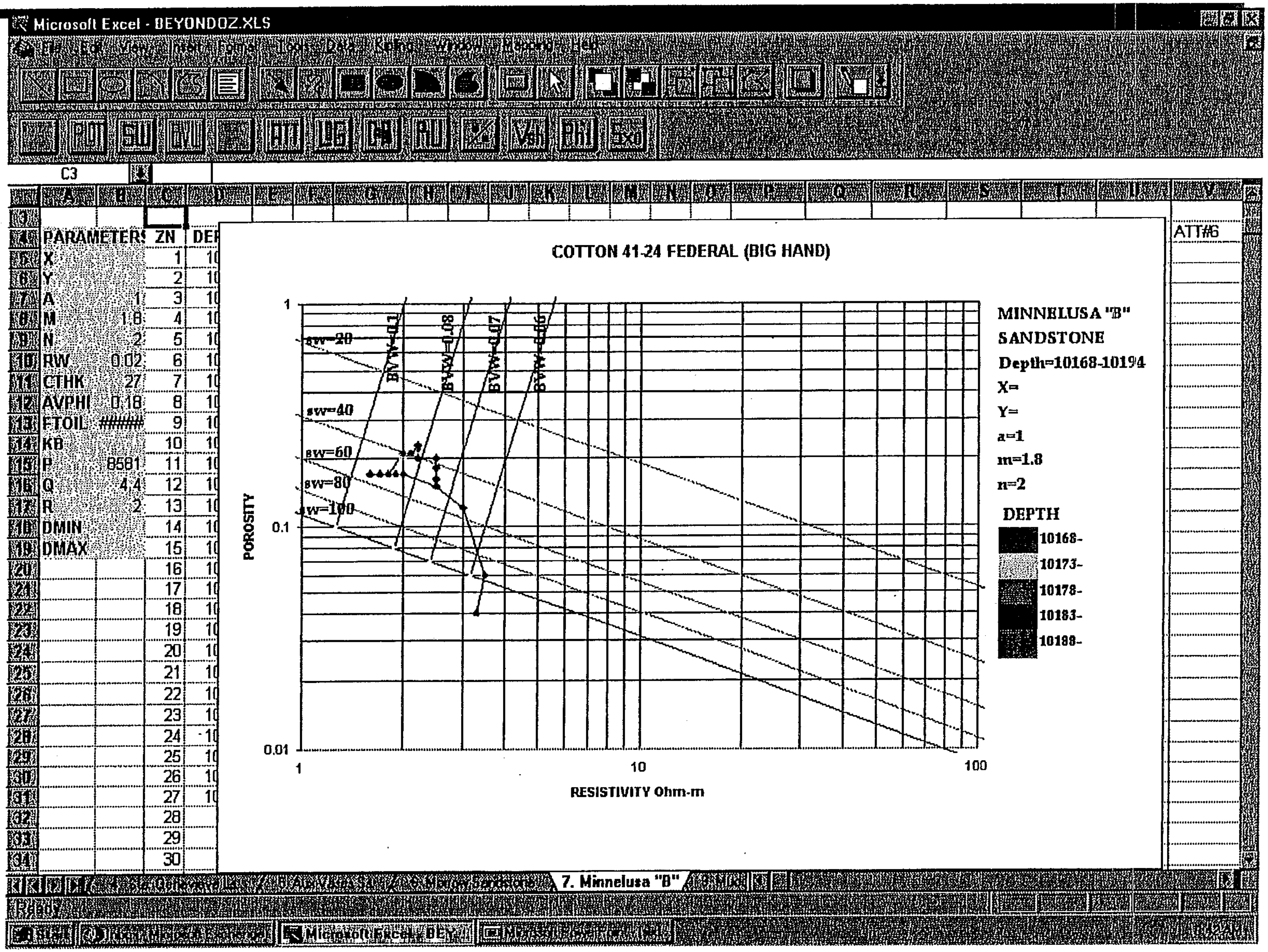
5. Aux Vases Sandstone



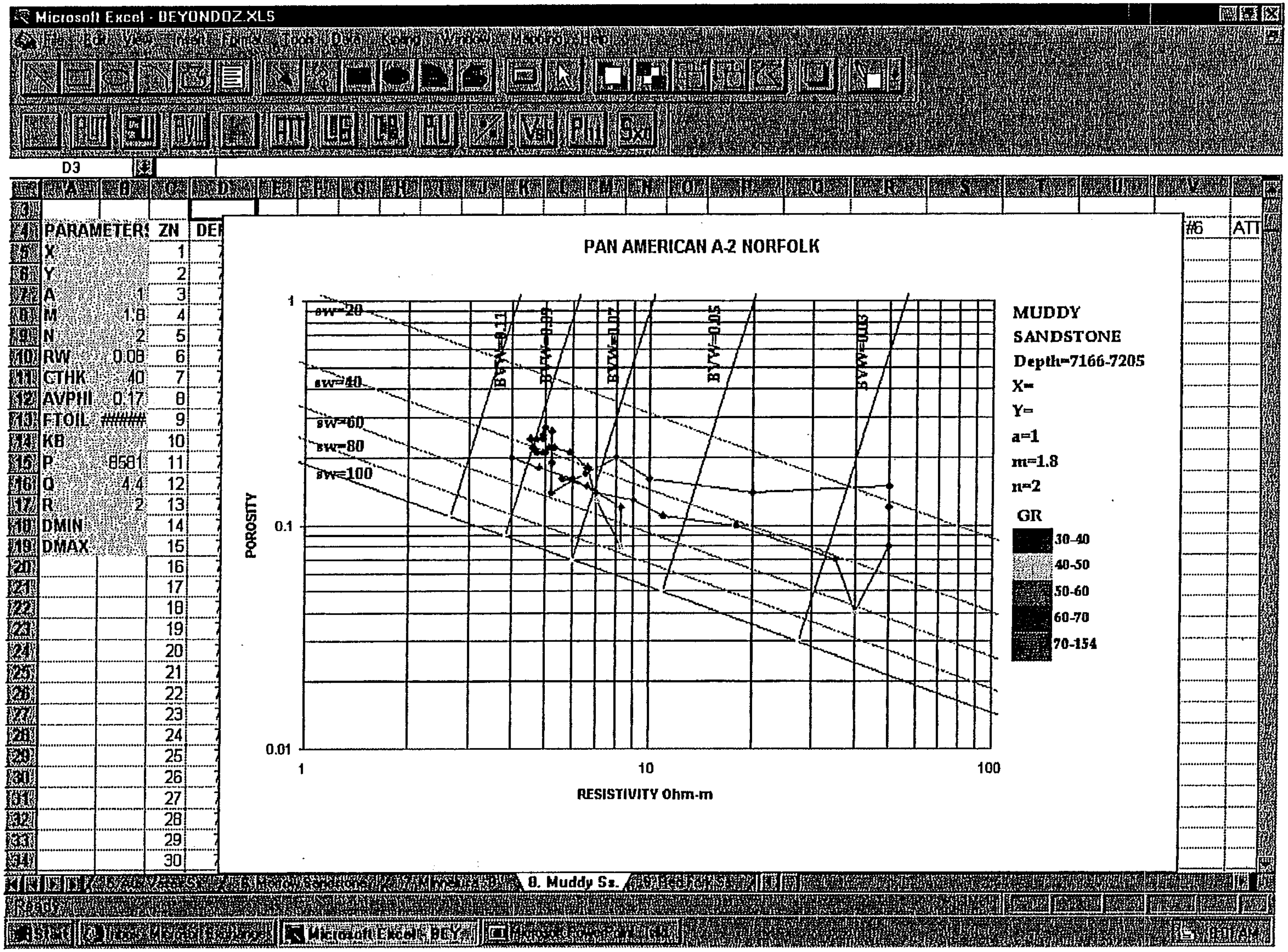
6. Morrow Sandstone



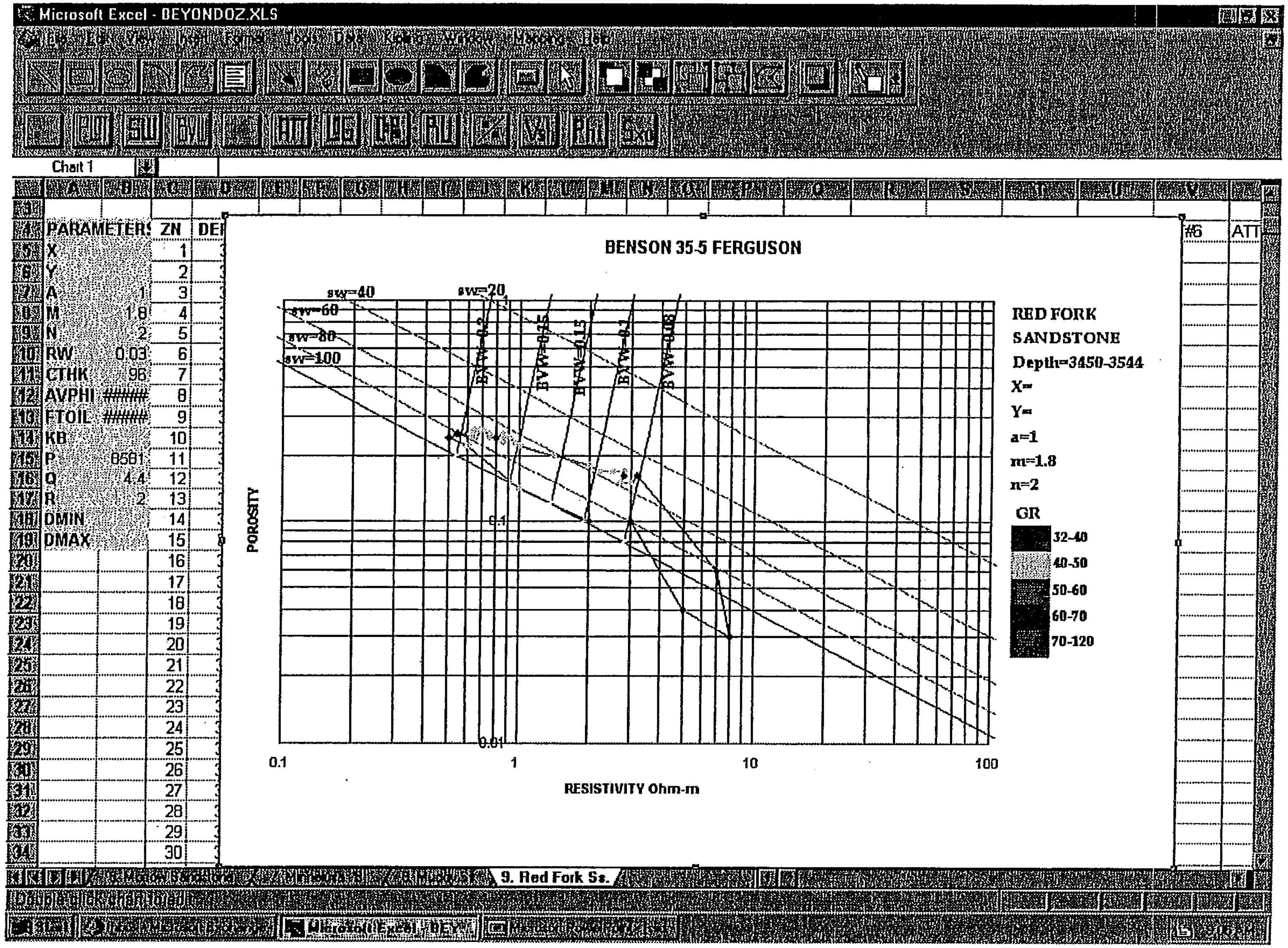
7. Minnelusa "B" Sandstone



8. Muddy Sandstone



9. Red Fork Sandstone



Task 4. Technology Transfer

Subtask 4.1. Three workshops will be held to inform participating operators of progress and to demonstrate software.

Workshop notes and software demonstrations have been presented to participants in day-long meetings as lectures using a hands-on format and prototypes of PfEFFER 2.0 and PfEFFER Pro (PfEFFER 1.1). Workshops were also used to present preliminary findings of new applications of PfEFFER, to get feedback on the use of the software, and to discuss plans.

Workshops provided for participating companies and BDM include:

1. PfEFFER Mid-Year Meeting, December 17, 1996, Lawrence, Kansas (see copy of volume in Appendix)
2. PfEFFER August 13, 1997 Review Meeting (see copy of volume in Appendix)

Other workshops held in conjunction with PTTC and KU Energy Research Center include:

1. February, 1997 meeting in Golden, CO for PTTC Directors
2. June 23, 1997, Well-Log Analysis on a PC using the PfEFFER Spreadsheet Program
3. November 7, 1997, same title as above (see copy of volume in Appendix)
4. November 13, 1997, Advanced Applications of Wireline Logging for Improved Oil Recovery Workshop - DOE Oil Recovery Projects sponsored by BDM, PTTC, and DOE.

Subtask 4.2. Writing and presenting papers on results and applications.

Other Presentations

(i) Kipling paper presented at Gulf Coast Section - SEPM, Houston, TX (December 11, 1997) (See copy in appendix.)
(ii) Demonstration of PfEFFER at PTTC Workshop, Golden, CO (February, 1997)
(iii) Present paper in Fourth International Reservoir Characterization Technical Conference sponsored by U.S. DOE and BDM-Oklahoma Inc./NIPER, Houston (March 2-4, 1997). (See copy of paper in Appendix.)
(iv) Present paper at Twelfth Oil Recovery Conference inn Wichita (March 10-12, 1997)
(iv) Two oral presentations at Annual AAPG/SEPM Meeting in Dallas (April, 1997) (See copies of abstract in appendix.)
(v) Demonstration of PfEFFER at Phillips workshop (April, 1997)
(vi) Technical presentation in Casper, Wyo at Wyoming Geological Society (December, 1997)

Other Technology Transfer

Aquifer application. The Geohydrology Section at the Kansas Geological Survey used a prototype of the cross section module to characterize the Arkansas River aquifer in Kansas (Young, Grauer, and Whittemore, 1997; see copy in Appendix). Lithologies were numerically coded from descriptions of auger drill holes and systematically used via PfEFFER cross section module to construct a series of cross sections along and across the river valley corridor. Numerous well columns color coded to lithology reveal vertical and lateral patterns of varying aquifer quality. The results and the software were shared with the ground water management districts.

Digital Well Log Analysis Project for Kansas (Kansas Virtual Geology - KVG) and Petroleum Re-Exploration in the Mature Producing Areas. The availability of PfEFFER was instrumental in launching an initiative in Kansas to collect digital well log data from operators to demonstrate the usefulness of having digital log data for geologic investigations. The following are excerpts from the KVG project description.

The petroleum geoscience enterprise is evolving as the result of maturing concepts in stratigraphy and sedimentation, access to digital information, and improved utilization of expanding and more powerful technology. New technology such as 3-D seismic has swept through the industry as a source of vital information used to target exploration prospects. However, quantitative processing and visualization of abundant wireline logs in mature producing areas such as the Midcontinent may serve as an equally powerful exploration tool to help to effectively isolate subtle petroleum accumulations that have been overlooked or bypassed. The particular enterprise is coined "reexploration."

Many geological concepts important in Midcontinent petroleum exploration have matured over many years of development and refinement, e.g., genetic stratigraphy and structural reactivation and its influence on sedimentation. Correlation and mapping of temporally distinct genetic stratigraphic units had been used to reconstruct details of paleogeography, shelf and basin configurations, and lithofacies. Processing and visualization of appropriate digital well log data can be used to refine information on lithofacies and provide new perspectives of pore and fluid types, all critical components in assessing reservoir development or its proximity.

Kansas Virtual Geology (KVG) is an endeavor to develop a set of digital type logs for Kansas and to facilitate processing and imaging of digital wireline logs to assist petroleum exploration. Operators are being asked to donate digital LAS (log ascii standard) files and, in turn, receive correlated color image strips of the gamma ray curve and a color image lithologic column, if neutron and density porosity logs and photoelectric curves are available. The color image lithology column is constructed at a scale of 1"=100 feet. The color image logs will also be accessible from the Survey WWW internet home page, http://www.kgs.ukans.edu. Opportunities for comment on the stratigraphic classification and nomenclature are available via e-mail. PfEFFER is a key component in this initiative, making it possible to do much of the analysis on a desktop PC.

Regionalized Variable Analysis of Genetic Stratigraphic Units. Validation and testing of sediment accumulation regions (SARs) and their boundaries was evaluated using PfEFFER generated cross sections. Internal stratigraphy and lithologies associated with an Upper Pennsylvanian stratigraphic interval were revealed on a regional, 300-km long color gamma-ray cross section (Figure 8). Each well was also accompanied by neutron-density porosity logs to provide lithologic control. Gamma ray logs were digitized from 25 wells within the interval of interest (Oread Limestone to top Marmaton Group), ranging in thickness from 100 to 350 meters (See cross section below). Well logs are digitized by scanning the logs into TIFF files which were importing into Neuralog to digitize the log image. These digitized log ascii standard files were then read into PfEFFER.

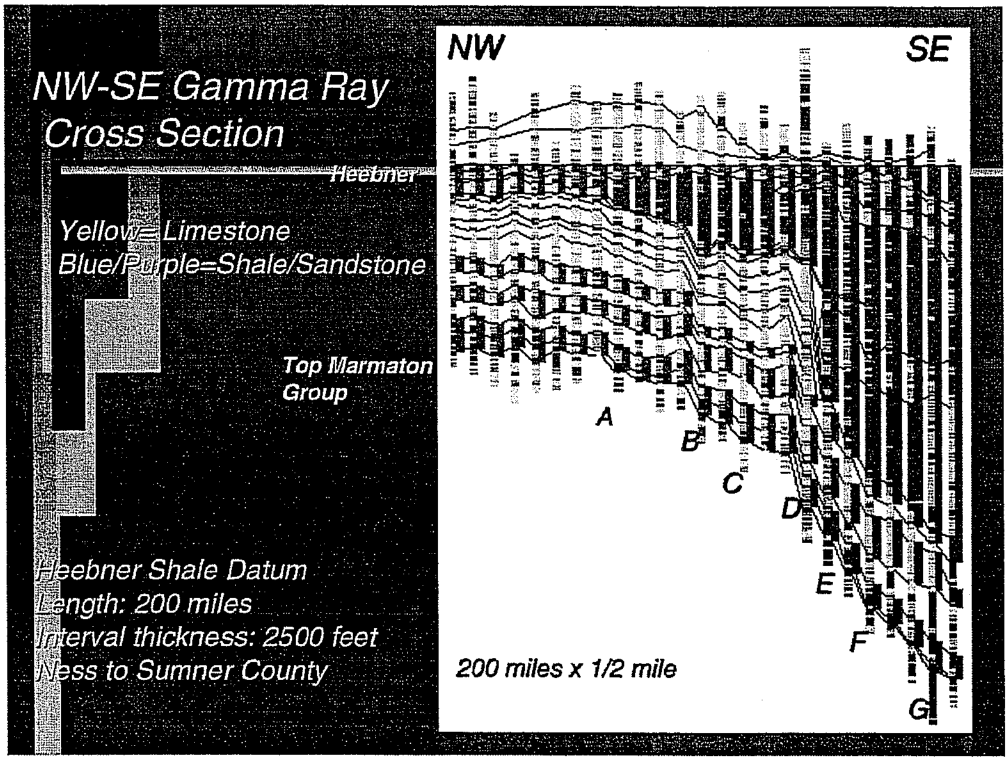


Figure 8. Northwest-southeast stratigraphic cross section (Ness County to Sumner County, Kansas). Datum is base Heebner Shale (top Muncie Creek Genetic Set). The section length is 200 miles (320 km). Vertical Scale is 1" = 30 ft. Vertical exaggeration is approximately 1100 times. Natural gamma ray data presented originally in color. Warmer and lighter colors correspond to lower gamma ray. Light gray intervals are limestone and dark gray corresponds to clastics. Correlation lines connect correlatable condensed sections in GSUs with a few exceptions. Previous work has established correlation of wireline logs with numerous cores and outcrops. Biostratigraphic correlations, where available, have confirmed correlations. Cross section was generated using PfEFFER software.

Publications (During Contract Period)

Bhattacharya, S., Gerlach, P., Carr, T., Guy, W., Beaty, S., Franseen, E., 1997, Cost-effective PC-based reservoir simulation and management - The Schaben Field (Mississippian) Ness County, Kansas: Proceedings of the Twelfth Oil Recovery Conference, Wichita, Tertiary Oil Recovery Project, The University of Kansas, p. 39-58.

Bohling, G.C., Doveton, J.H., and Watney, W.L., 1996, Systematic identification of sequence stratigraphic units from wireline logs: in, Pacht, J.A., Sheriff, R.E., and Perkins, B.F., Stratigraphic Analysis Utilizing Advanced Geophysical, Wireline, and Borehole Technology for Petroleum Exploration and Production: Seventeenth Annual Research Conference, Gulf Coast Section, Society of Economic Paleontologists and Mineralogists Foundation, Houston, Tx., p. 29-37.

Bohling, G.C. , Doveton, J.H., and Hoth, P., 1997, Probabilistic classification and prediction of facies types in a mid-continent cretaceous deltaic-marine sequence from petrophysical log descriptors using a cmac procedure (Abs.): Proc. IAMG Conference, Barcelona, Spain.

Bohling, G., Doveton, J., Guy, B., and Watney, L., 1997, PfEFFER 1.1 Manual, 133 p.

Carr, T.R., Gerhard, L.C., Watney, W.L., Gerlach, P., Adkins-Heljesen, D., Guy, W., Kruger, J.M., Stalder, K., Bhattacharya, S., and Weeks, W., 1997, Digital petroleum atlas report - 1996, URL — www.kgs.ukans.edu/PRS/publication/OFR97-14/DPA-A96-Abs.html

Carr, T.R., Bhattacharya, S., Franseen, E., Gerlach, P., Guy, W., Doveton, J., Watney, W.L., Adkins-Heljesen, Hopkins, J., Beaty, S., Reynolds, R., Vossoughi, S., and Willhite, G.P., 1997, Improved oil recovery in Mississippian carbonate reservoirs of Kansas — near term— Class 2; annual report, Year 2, 235 p., URL — www.kgs.ukans.edu/PRS/Info/WebPubs97-24.html

Carr, T.R., Adkins-Heljeson, D., Gerlach, P.M., Gerhard, L.C., Guy, W.J., Kruger, J.M., Watney, W.L., 1997, The Kansas Geological Survey's Digital Petroleum Atlas (DPA) Project: SPE Preprint 38825, p. 771-778.

Doveton, J.H., Guy, W., and Watney, W.L., 1997, PfEFFER - Log analysis spreadsheet solutions for reservoir engineering and petroleum geology: Proceedings, Twelth Oil Recovery Conference, Wichita, KS, p. 85-90.

Doveton, J.H., Guy, W.J., Watney, W.L., 1997, The integration of pore measurements into log analysis pattern recognition procedures: Methods and examples: AAPG Convention Abstracts, Dallas, Texas, p.A29.

Doveton, J.H., Guy, W.J., Watney, W.L., Bohling, G.C., and Bhattacharya, S., 1997, PfEFFER: The integrated analysis of wireline logs and reservoir data in a spreadsheet environment: Advanced Applications of Wireline Logging for Improved Oil Recovery Workshop, Midland, November 13, 1997, BDM, DOE, PTTC, p. 137-150.

Guy, Willard J., Carr, T.R., Franseen, E.K., Bhattacharya, S., Beaty, S. ,1997, Combination of Magnetic Resonance and Classic Petrophysical Techniques to Determine Pore Geometry and Characterization of a Complex Heterogeneous Carbonate Reservoir: AAPG Convention Abstracts, Dallas, Texas.

Young, D., Grauer, J., and Whittemore, D., 1997, Upper Arkansas River corridor study: Progress on Lithologic characterization of unconsolidated deposits in the study area with emphasis on Kearny and Finney Counties: Kansas Geological Survey Open-File Report 97-43, 20 p. (geohydrology application of PfEFFER)

Watney, W.L., Guy, W.J., Doveton, J.H., Bhattacharya, S., Gerlach, P.M., Bohling, G.C., and Carr, T.R., in press, Petrofacies Analysis - A petrophysical tool for geological/engineering reservoir characterization: Precedings of the Fourth International Reservoir Characterization Conference, Houston, March 2-4, 1997.

Watney, W. L., Kruger, J., Davis, J.C., Harff, J. Olea, R.A., and Bohling, G.C., in review, Validation and Testing of Regional Sediment Accumulation Regions for Pennsylvanian Genetic Stratigraphic Units in Kansas, U.S.A., Computer Basin Analysis, Springer-Verlag. (exploration application of PfEFFER)

Watney, W. L., Davis, J.C., Kruger, J.M., and Harff, J., 1997, Sediment accommodation regions: Fragmentation of a subsiding shelf: AAPG Convention Abstacts, Dallas, Texas, p. A123. (utilization of PfEFFER color cross section module for regional stratigraphic visualization)

PfEFFER related web sites

PfEFFER home page: http://crude2.kgs.ukans.edu/PRS/software/pfeffer1.html
Digital Petroleum Atlas (DPA) home page: http://crude2.kgs.ukans.edu/DPA/dpaKansas.html
Terry Field page in DPA: http://crude2.kgs.ukans.edu/DPA/Terry/terryMain.html
Schaben Field page in DPA: http://crude2.kgs.ukans.edu/DPA/Schaben/schabenMain.html

Summary

With the support of this contract PfEFFER is now able to perform high-end petrophysical well log analysis in an interactive spreadsheet environment providing the user with considerable tools for reservoir characterization. Applications range from initial reservoir delineation and to more extensive characterization of a single or multiple reservoirs and wells. Data are easily organized as worksheets and workbooks. Characterizations can be integrated with special core analyses such as the utilization of the capillary pressure module. Synthetic petrophysical reservoirs can be developed using the forward modeling module to compare with actual log response. Flow unit designation is facilitated through the use of several modules including a spreadsheet column for manual classification of each depth increment. A cluster analysis module is available to help classify depths with similar variables. Cross section and mapping modules provide the means to examine stratigraphic and spatial variations in reservoirs and flow units. GRIDforSIM links PfEFFER to reservoir simulators to facilitate testing the characterization. PfEFFER now provides an inexpensive option for users to conduct an integrated geologic-engineering investigation of a reservoir.

While reservoir production/exploitation applications are clearly defined for PfEFFER, it is also apparent that PfEFFER can be used in petroleum exploration to filter through large stratigraphic intervals that may contain prospective reservoirs. Longer depth intervals can be segmented and processed as separate worksheets to reveal possible overlooked and bypassed pay in complex reservoir situations. The cross section option permits color visualization of any depth-coded variable over small to large depth intervals (several 1000 ft) and provide new insights into reservoir systems including potentially evaluating fluid migration pathways in basin via hydrocarbon "show" analysis. PfEFFER is a general purpose technology to efficiently and effectively handle digital log data for a wide variety and scale of geoscientific problems.

Applications and technology transfer in general have demonstrated that bulk volume water is critical to assessing reservoir quality and producibility. "Rules of thumb" porosity and water saturation cutoffs were acceptable to use in the past as reservoirs were newly discovered. In contrast, today a refined understanding of the reservoir pore type and reservoir conformance and continuity are essential to identify appropriate recovery technologies, reduce risk, and identify opportunities in reservoirs that exhibit complex pore types. Well log analysis is a crucial element in the characterization process including a quantitative description of the pore and geometry of the flow unit. Economics and resources today demand that these analysis be delivered inexpensively, consistently, and effectively on the desktop and that they can be easily integrated into technologies that are necessary in decision making. Reservoir simulation is the ultimate tool to test the characterization and to apply the results toward evaluation and design of reservoir management options. PFEFFER 2.0 and PfEFFER Pro provide tools to assist practical attainment of reservoir simulation.

Thousands of Pickett cross plots have been constructed and compared with production, tests, and analyses including capillary pressure and nuclear magnetic resonance. While variations of producing reservoir properties are significant, patterns seen on the Pickett crossplot are more limited and help to describe the reservoir and place it in perspective of other locations or other reservoirs. Even where complex pores develop or where the effects of microporosity and clay lead to high bound water and apparent water saturation, delineation of effective pay can be obtained via the Pickett crossplots. Additional tools provided in PfEFFER further the modeling process of the reservoir.

Future Options

1. Relative Permeability -- Many use PfEFFER not only to establish accurate porosity and saturation data but also for identification and evaluation of economic/productive intervals, i.e., "pay." Criteria for when intervals are pay or non-pay are diverse and range from the fundamental variables of hydrocarbon porosity (cumulative storage), and hydrocarbon and water flow (cumulative flow) to the economics of produced water handling and pump costs in a given field. While comprehensive analysis of pay is beyond the function of PfEFFER, a module that shows hydrocarbon storage and hydrocarbon and water flow for each one foot interval would aid in completion and perforation decisions and reservoir characterization. Use of PfEFFER on a laptop PC could allow completion and perforation decisions to be performed during or immediately after logging runs. Coupled with the mapping module, cross-sections of cumulative storage and flow would aid in understanding the spatial distribution of productive intervals. Integrating storage and flow data with other log responses would also help in understanding the relative contributions of specific intervals and aid in identifying log signatures for different types of storage and flow units (contributed by Alan Byrnes, KGS petrophysicist).

2. Develop and test concepts of permeability classification and fracture detection using the KIPLING based on CMAC (cerebellar model arithmetic computing) a potential module in PfEFFER. Application would be an additional step toward more comprehensive and consistent reservoir characterization. Calibrate analyses with special core analyses of complex sandstone and carbonate reservoirs.

> Examine the use of KIPLING beyond (Bohling, Doveton, and Watney, 1996) its application to classifying lithofacies and genetic stratigraphic units.

4. In the GRIDforSIM module create a "Zero" template option that can be applied to multiple grids for consistent limiting of grids to honor boundaries of the reservoir.

5. Develop a "VOLUMETRICS" module in PfEFFER Pro to evaluate pre-conditions to be used before undertaking a fluid-flow reservoir simulation. This would also be a stand along module that could be very useful as an initial calculation of remaining unrecovered oil. Also, if calculations show that the input parameters are incorrect, it may minimize the iterations between simulation and parameter modification.

This module would provide --

1) "quick look" calculations to examine reservoir volumetrics and

2) comparison of results with recovered fluid to determine if additional adjustments are needed to net pay and fluid saturation cutoffs.

Volumetric calculations would include--

1) residual oil in place,

2) residual oil saturation, and

3) residual mobile oil.

6. Continued calibration and integration of PfEFFER analysis with capillary pressure, magnetic resonance imaging, and special core and fluid analysis (relative permeability and PVT). Apply to demonstration projects in collaboration with

1) industry partners and/or

2) DOE's reservoir management programs.

7. Extend LOG module to include --

1) color solutions for lithodensity and spectral gamma ray logs,

2) prepare standard well display and printing options, and

3) integrate results with CROSS SECTION module.

8. Facilitate correlation of flow units using "petrophysical Fischer plot."

9. Continue to revise PfEFFER coding to be compatible with latest version of Excel.